R&D Report and FY19 Proposal
- eRD6 Tracking & PID Consortium -

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(For the eRD6 Consortium)

January – July 2018 / BNL, FIT, INFN, SBU, UVA

R&D REPORT

TRACKING

Overview – Current Tracking R&D

- BNL
  - Optimized zigzag strip readout
  - Infrastructure for TPC R&D
- FIT, UVA
  - Assembly of two full-size, low-mass forward tracker prototypes
  - Beam test at Fermilab June/July 2018
- SBU
  - Assembly and beam test of TPC prototype at Fermilab July 2018

Optimized Zigzag Readout (BNL)

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BNL

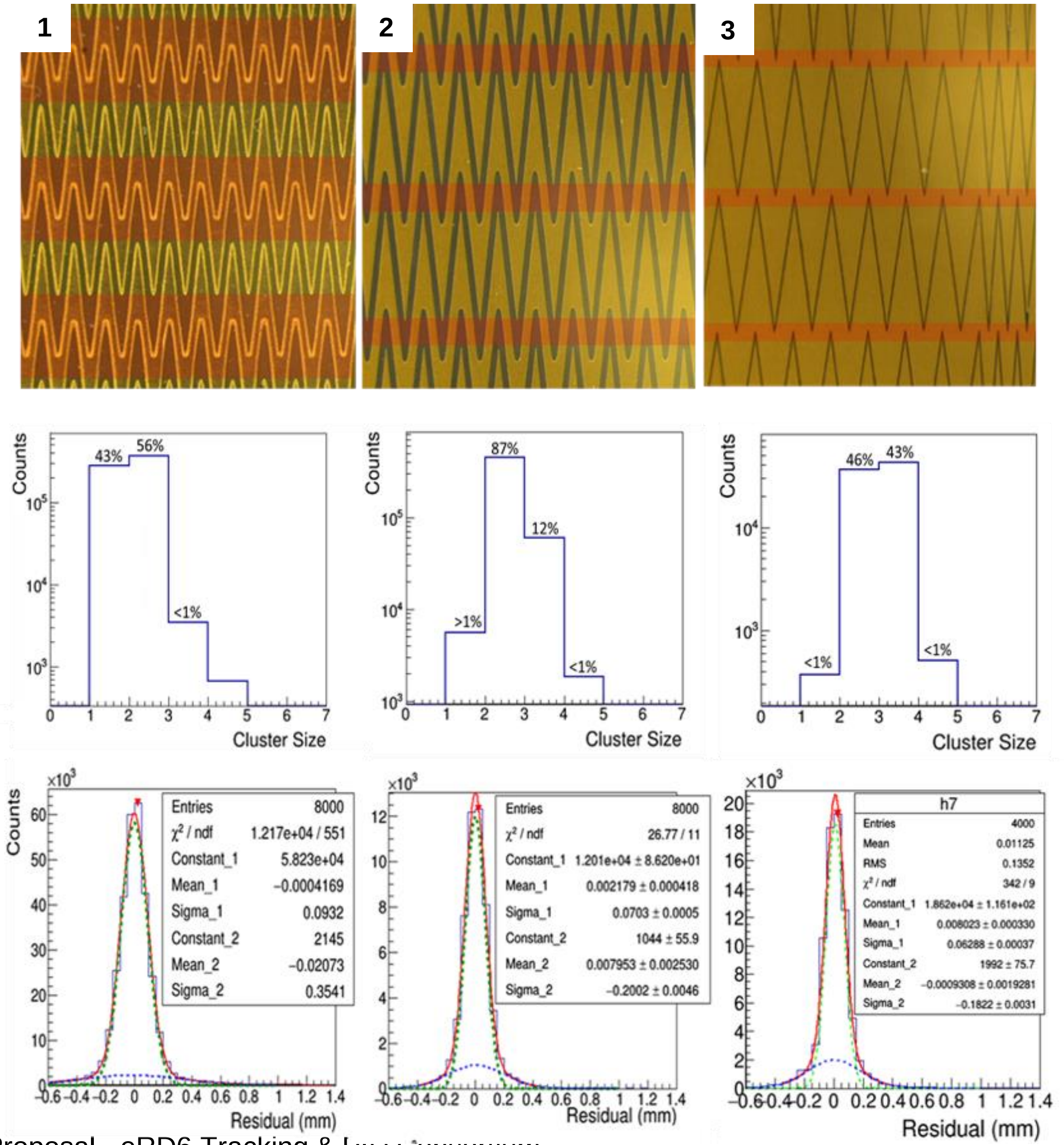
I. Characterizing Zigzag readouts using x-ray scans

ZZ pattern	1. Chemical Etch (un-optimized)	2. Chemical Etch (optimized)	3. Laser Etch (optimized, low gain)
pitch/period	2mm/0.5mm	2mm/0.56mm	2mm/0.5mm
Strip Overlap / Conductor coverage	40% / 66%	83% / 63%	87% / 90%
Gap width	82μm	84μm	22μm
Position Resolution / Efficiency due to removal of single pad hits	93μm (56% eff.)	70μm (99% eff.)	63μm (100% eff.)

- There is a clear trend in improved performance from the zigzag readouts as the zigzag design and the manufacturing techniques have progressed over the last few years.

- In particular, the use of laser ablation to form the zigzag electrodes has allowed greater overlap between neighboring pads while maintaining a high level of conductor coverage on the readout plane, which is mostly responsible for this improvement.

- So far, the results with laser ablation have only been achieved over a relatively small area of the readout since ~20% of pads are shorted to a neighboring pad. However, efforts are currently under way to address this manufacturing flaw.



Optimized Zigzag Readout (BNL)

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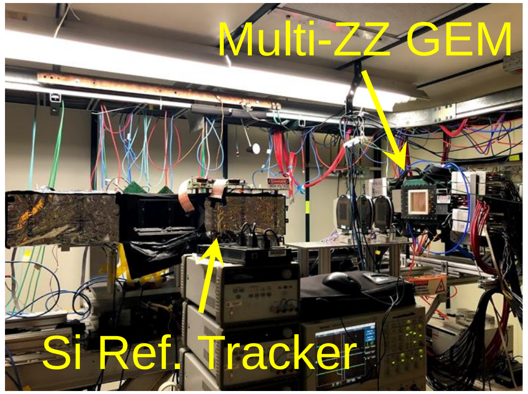
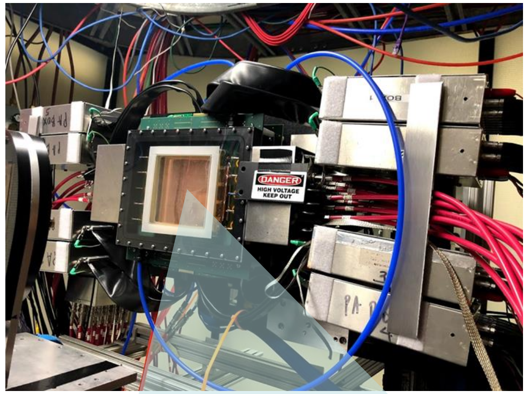
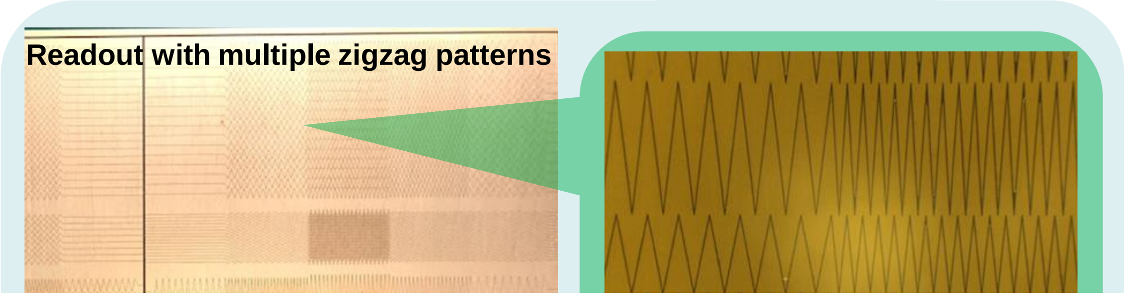
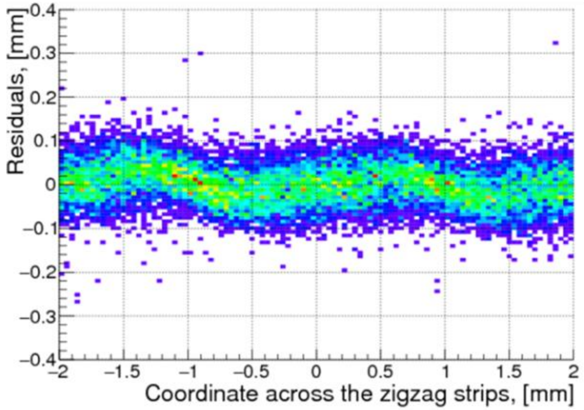
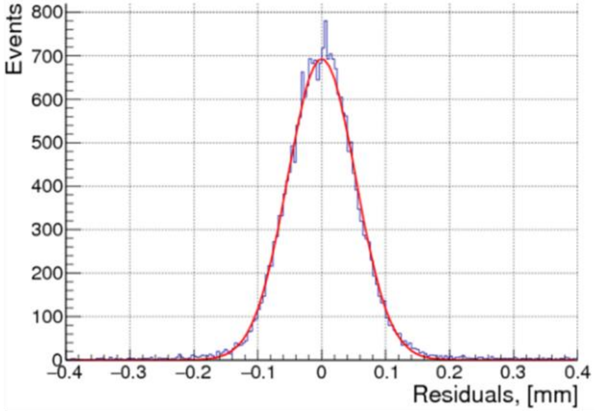
II. Beam test results from a 4-GEM planar detector equipped with a “Multi-zigzag readout”





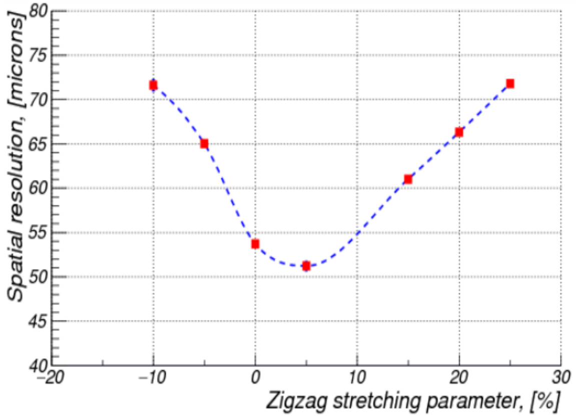






- Study multiple zigzag patterns (over a relatively broad range of geometric parameters) in a single PCB
- PCB generated using laser ablation
- Tested 4-GEM+multi-ZZ, Micromegas(MM)+multi-ZZ, and GEM+MM+multi-ZZ
- Systematic tests (eg, gain scan, scan of fields in gaps) with real tracks show very encouraging results

- Preliminary results with 4-GEM+multi-ZZ (2mm pitch, 0.4mm period, >90% interleaving, ~90% coverage) : suppressed DNL, and a position resolution of 52μm for normally incident tracks
- Stretching the zigzag pattern (such that neighboring pads overlap by some % of the pitch) shows a minimum for the spatial resolution at 5% --need further testing to explain
- TO DO: try different gases with different trans. diffusion; minidrift config. to measure angled tracks



TPC R&D Infrastructure (BNL)

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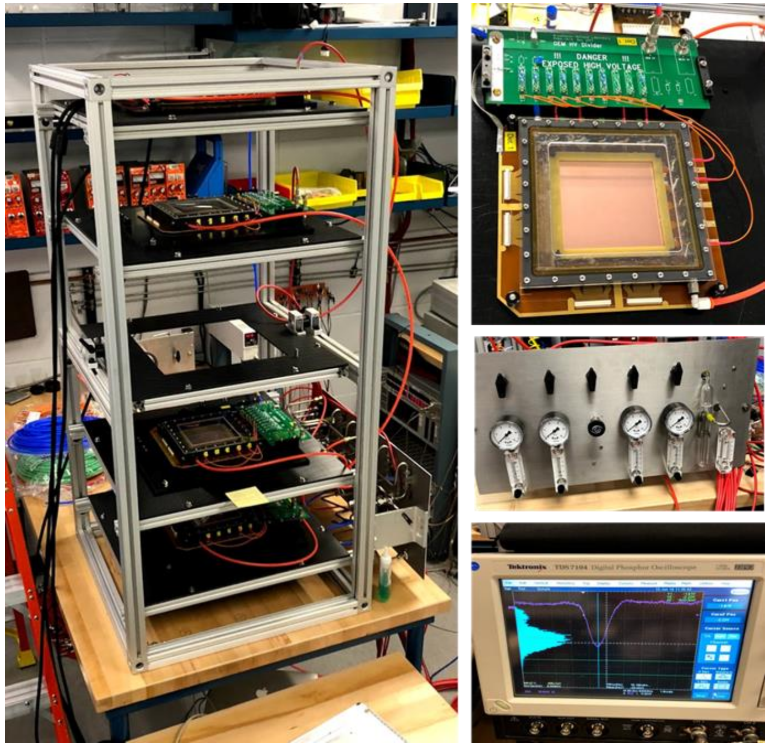
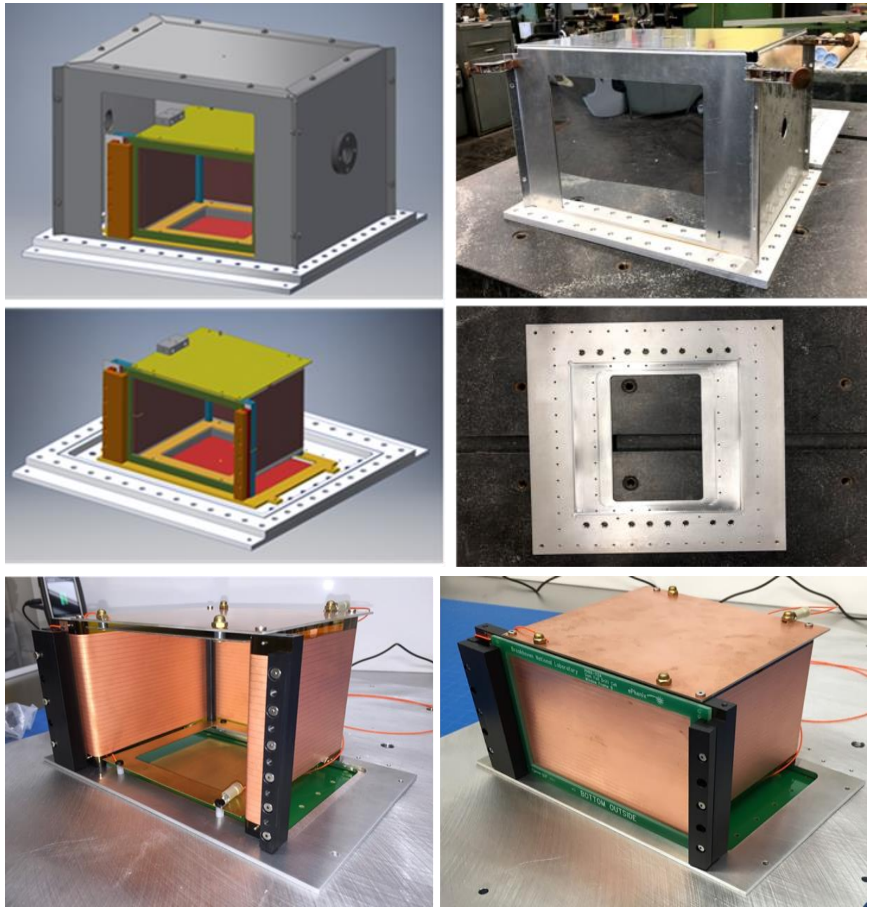
Just Completed GEM-based cosmic ray telescope



- Measure high res. ref. particle tracks in the lab
- 4 layer tracker with COMPASS X-Y readout
- Reconstructing track segments in a mini-drift config. (instead of space points) may substantially improve position resolution
- Recently used successfully by UVA and FIT collaborators at Fermilab beam test

Assembly of compact TPC prototype nearing completion



- The prototype can accept our r/o PCB template design / re-use TPC-Cherenkov prototype field cage
- HV testing the field cage within the enclosure is currently underway
- We expect to have the assembly complete within weeks

Small Prototype TPC (SBU)

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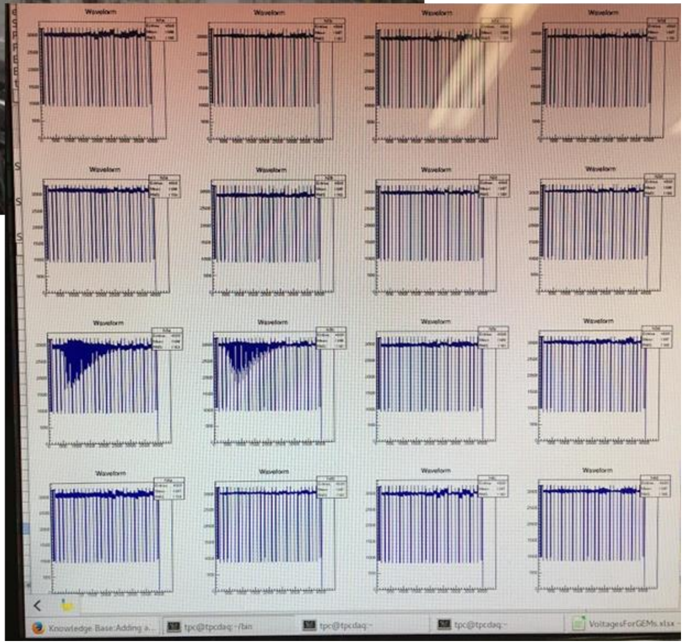
Test Beam



- Principle Goal: Drift Length Scan
  - >10000(30,000) triggers at 8 points spanning full length.
  - Highest statistics at end points.

Next steps: setting up for IBF measurements

Forward Tracker – Low-mass GEMs (FIT)

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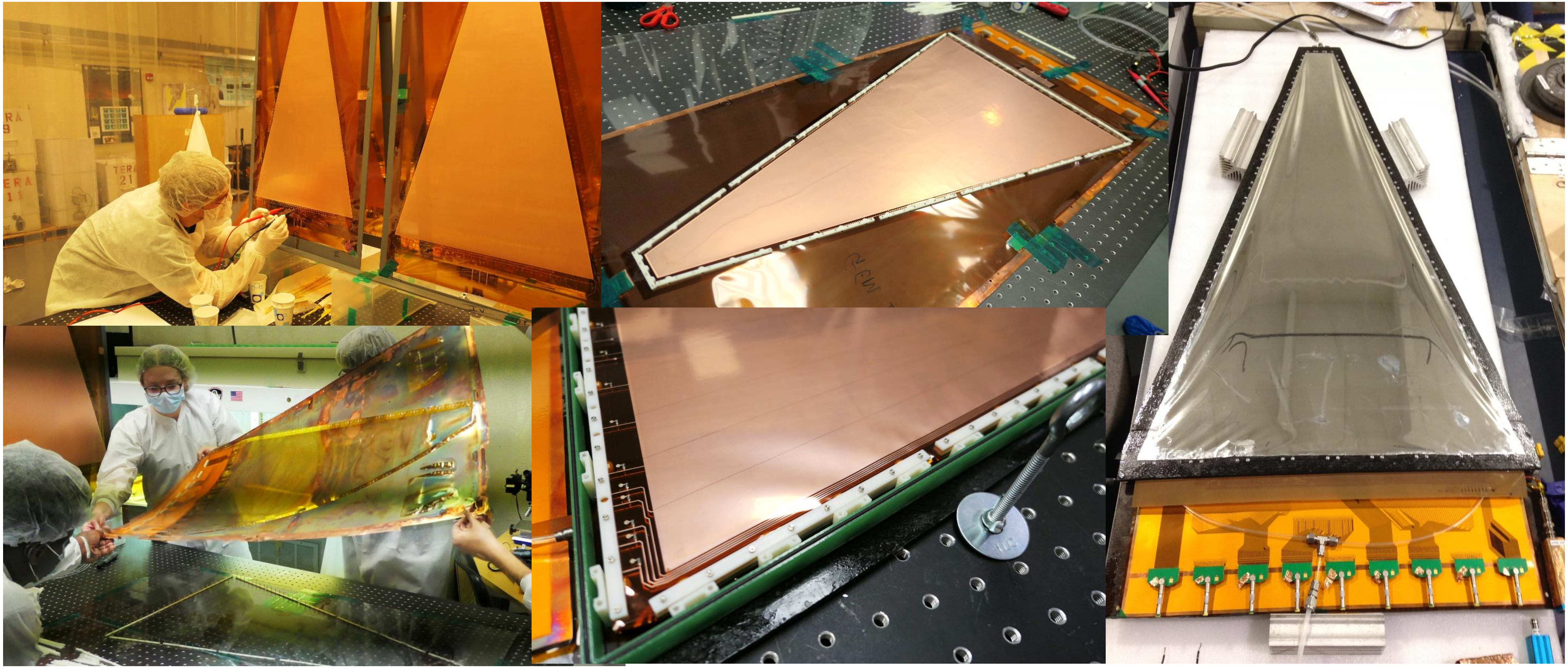
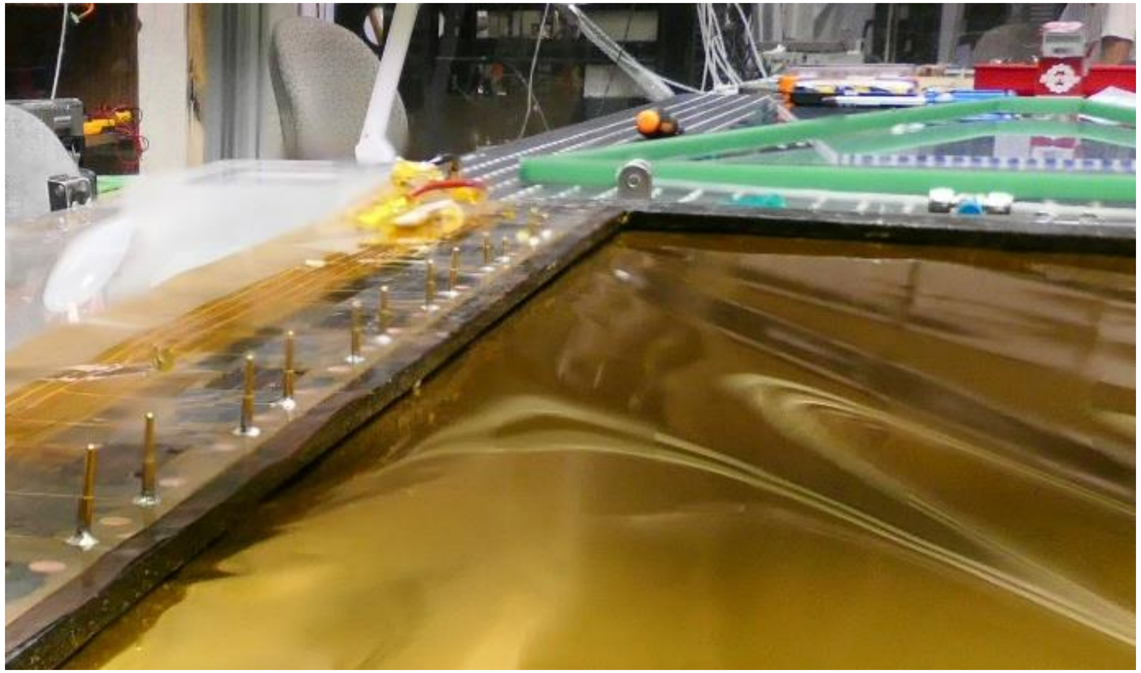
FIT

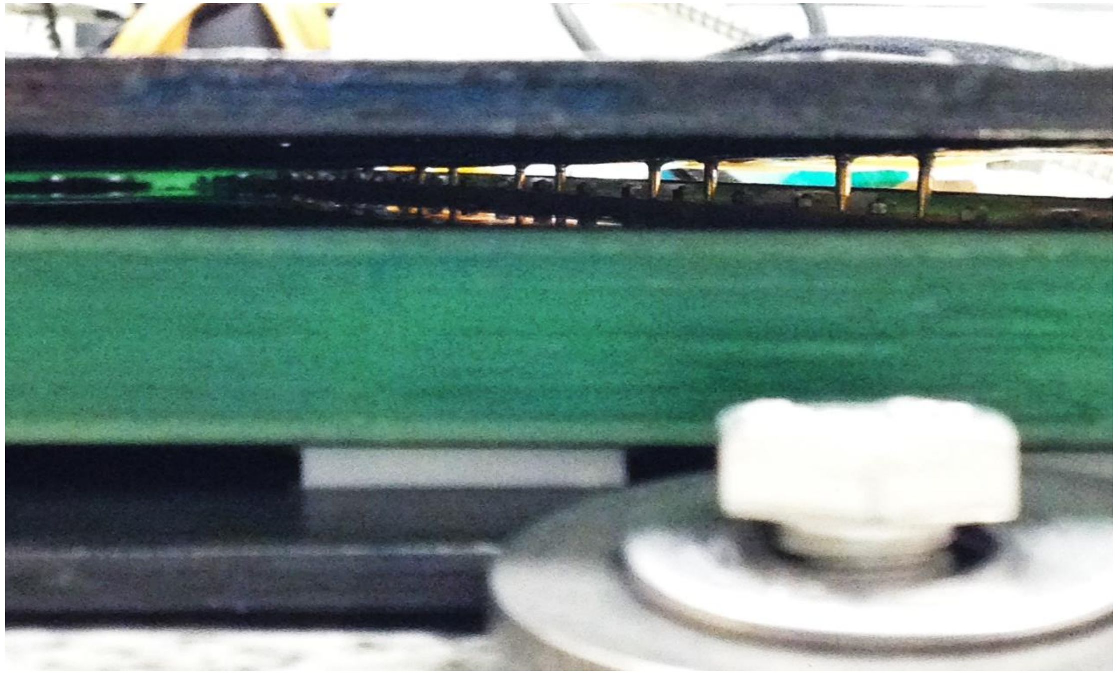
Initial assembly of **carbon-fiber frame prototype** and test:



Low-mass CF Frame GEM - Observations

- **Encouraging:**
  - HV foil with soldered spring-loaded pins that is glued onto CF frame works well for making contacts with foils in stack and suppling electric potentials to foils
  - CF frame doesn’t show any large deformation when stack is tensioned (no bowing)
  - No issues with conductivity of CF
  - Total chamber mass below 3 kg (w/ HV filter but w/o FE electronics)





Low-mass CF Frame GEM - Observations

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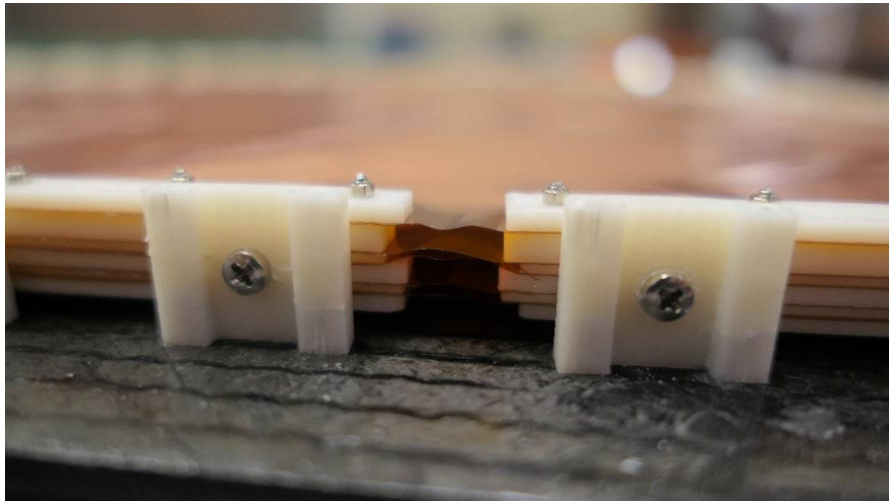
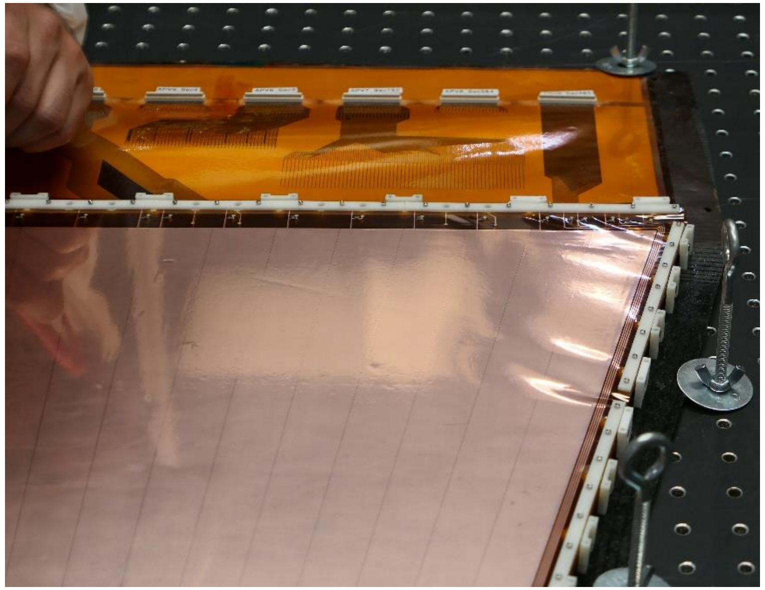
- **Problematic**:
  - Foils not perfectly flat after stretching; foils wrinkle in gaps b/w inner frames
  - Detector did not hold full voltage at FIT (HV trips and audible discharges); subsequently confirmed at FTBF
  - Low impedance “shorts” (1-2 MΩ) across drift & transfer-1 gap at FTBF
  - Al-Kapton entrance window can partially “collapse” onto drift foil at low gas flow
  - Chamber leaky



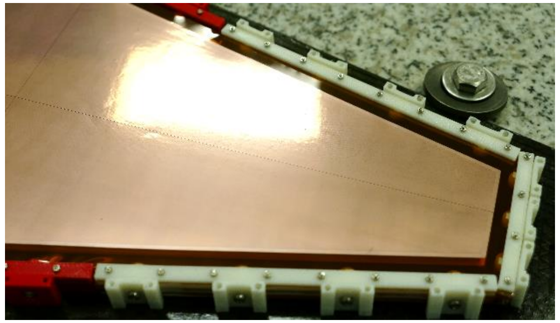


Low-mass CF Frame GEM - Issues

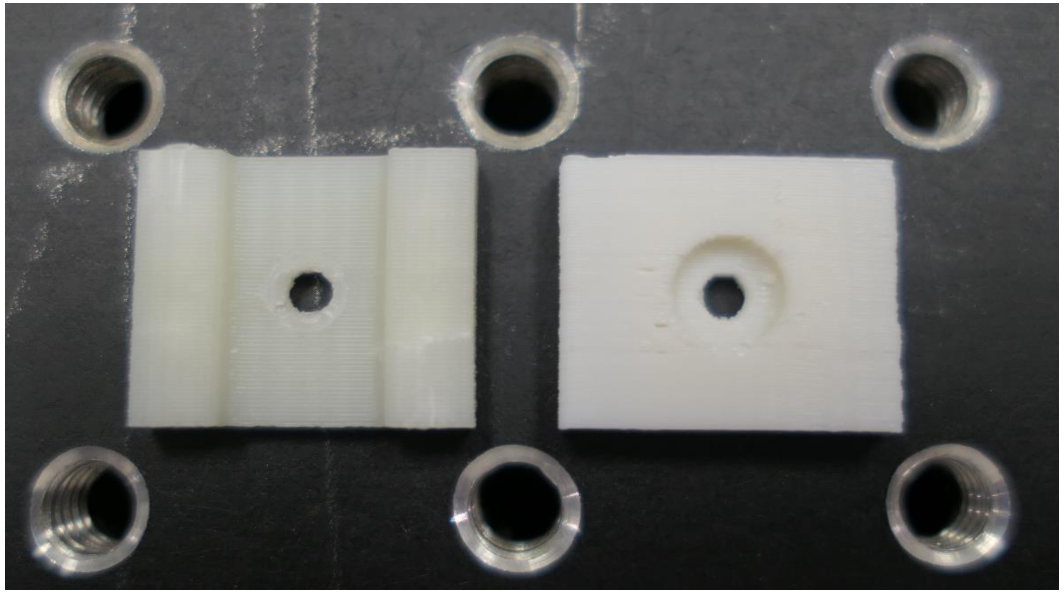
- Causes (our current hypotheses):
  - **Insufficient stretching** of the 5 foils in the stack reduces gaps (and increases E-field) or causes foils to touch in several HV sectors
  - **Gaps** between inner frame pieces on two long sides are design flaw
  - **3D-printed light ABS material turned out to be too soft** for making robust pull-outs that can withstand the forces that are apparently necessary for properly tensioning a 5-foil stack
    - Pull-outs bend inward, which reduces the stack tension, and even crack
    - Screws fastening CF frames against pull-outs cannot be tightened sufficiently before stripping the threads in the pull-outs

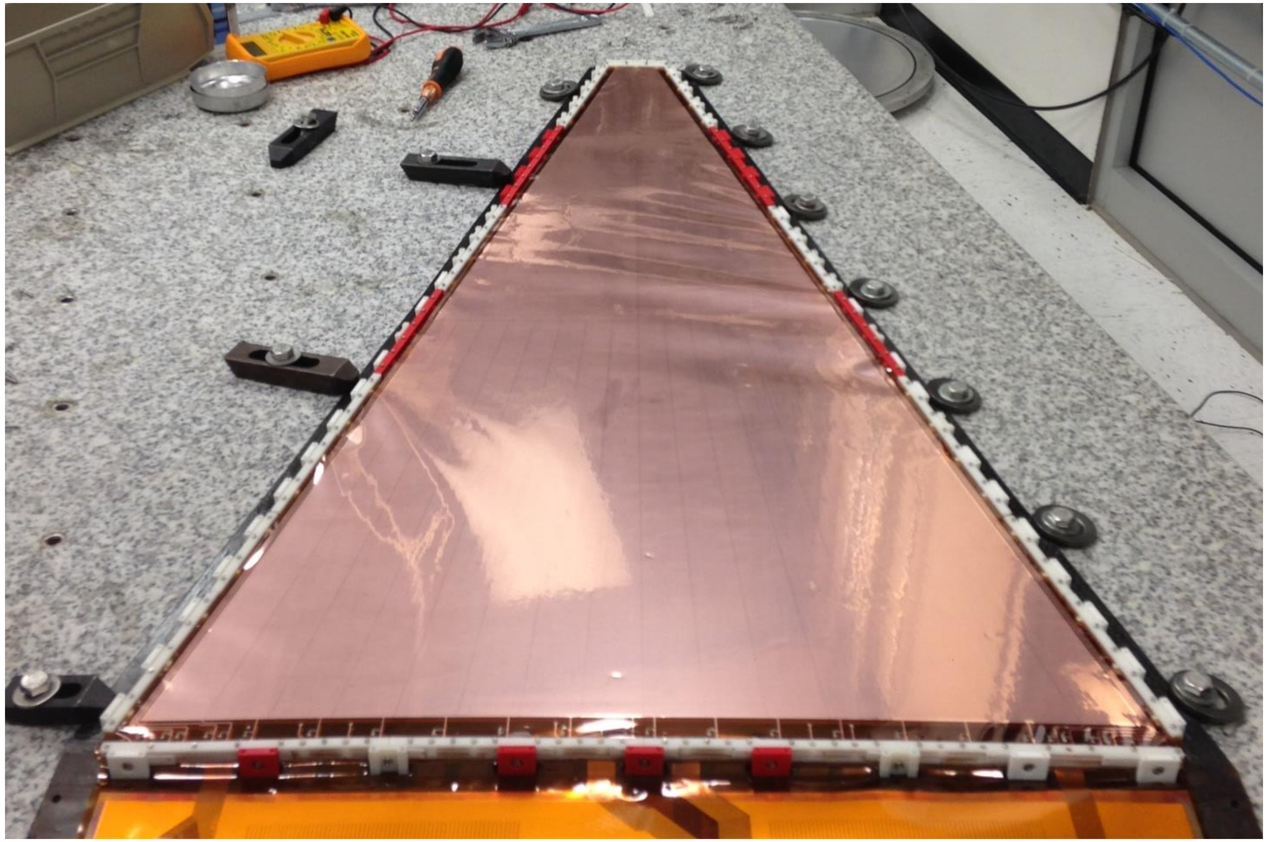
(Notes: Design is based on CMS detectors that use only 3 foils and stainless steel pull-outs; transfer-1 & induction gaps only 1mm wide.)

Low-mass CF Frame GEM - Remedies



- Already attempted (at FNAL)
  - Redesign & reprint some inner frames to remove 1cm **gaps**
  - Redesign & reprint pull-outs with a more solid design
- Future (FY19 cycle)
  - Machine pull-outs/frames from **PEEK**
  - Change gaps: 3/1/2/1→ 3/2/2/2 mm

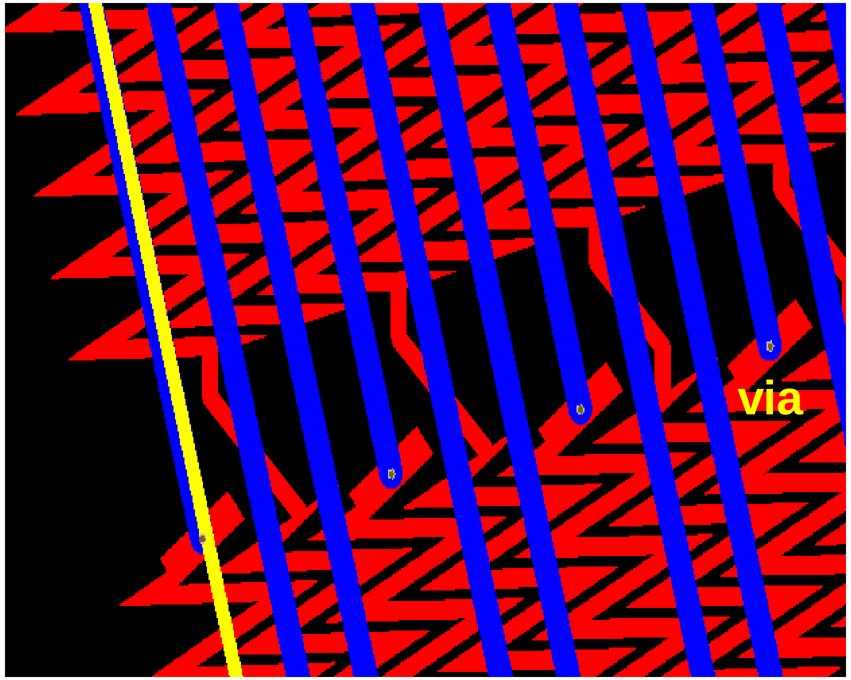


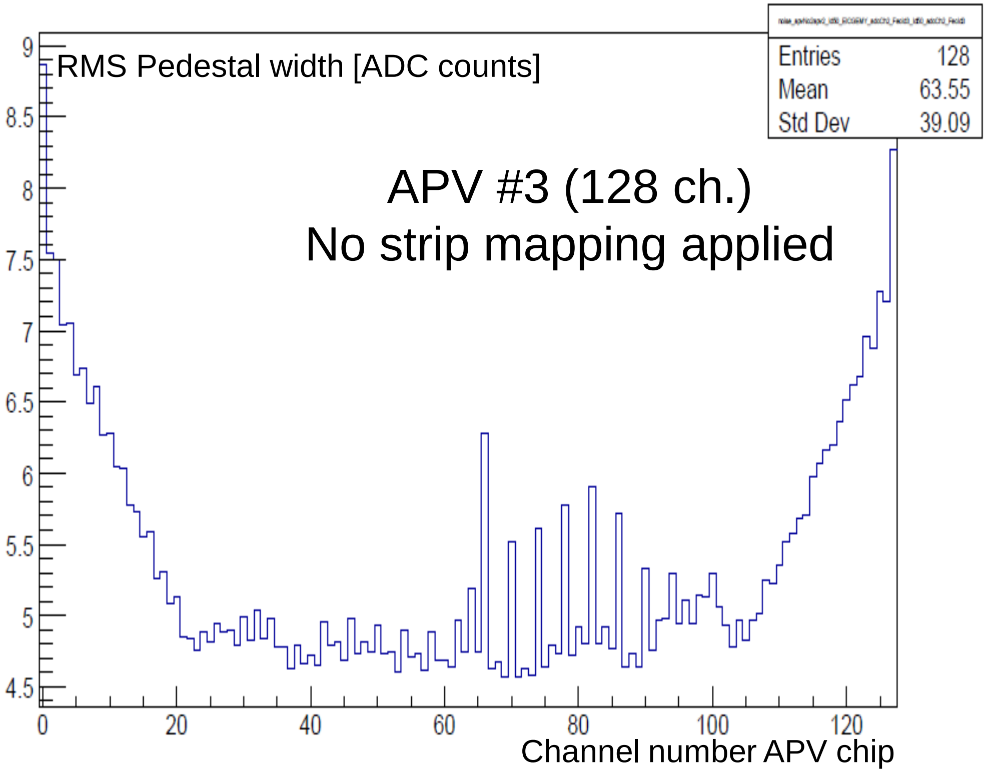


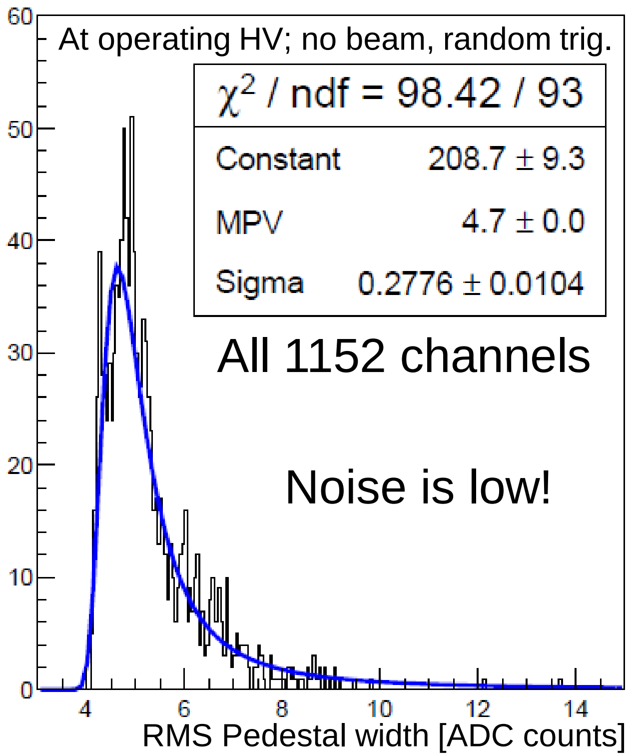
Low-mass CF Frame GEM – First Data

- Readout uses long zigzag strips with long signal traces on back of the readout foil to connect strips to FE electronics: high C, complex routing
- $\Rightarrow$ Noise and cross-talk are potential concerns
- Measured pedestals at various HV settings at FTBF; **find low noise**

i = 718 muA in HV divider







Low-mass G10 Frame GEM – Assembly (UVA)

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UVA

Main goals / challenges of the current R&D:

⇨ **Low Mass Detector:** All foils in the active area

- Drift Cathode & U-V strips readout foil are all foils
- No rigid PCB or honeycomb support in the active area (except 300 µm spacer grids)
- Entrance and exit gas window ⇨ uniform gap b/w inner layers

⇨ **Low Cost Support Frames:**

- External support frames (2 gas window + 2 top frames) locally produced at **lower cost** with commercial G10 material
- Inner frames, 3 GEMs + drift cathode frames with spacer grids ⇨ produced in Belgium (RESARM) at **a higher cost**
- **~ 30% total production cost saving**

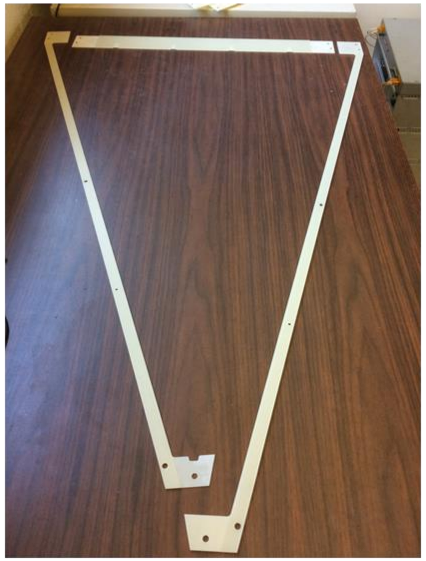
⇨ **Double sided zebra connection scheme:**

- Double the number of electronic channels to be readout from the outer radius of the chamber
- **No FE cards on the back or the side of the detector**
- No vias necessary on the readout strip foil ⇨ **thinner Cu layer for both U and V strips**

Common GEM Foil

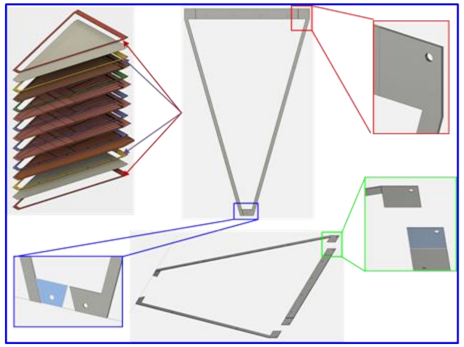
U-V strips readout foil

Low Cost Support Frames

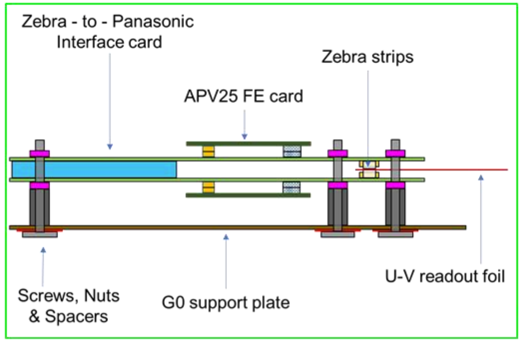


EIC-FT-GEM Prototype

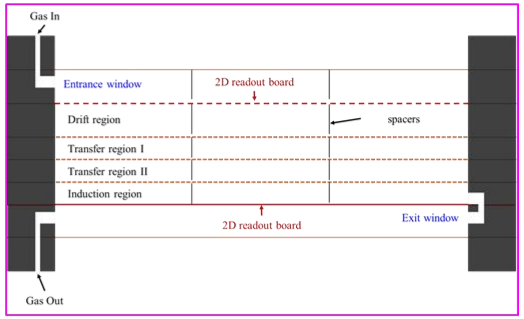
Hybrid of Low Cost & High performances Support Frames



Sketch of the double side zebra strip connection scheme for the U-V strip readout



Cross section of Low Mass / All Foils EIC-FT GEM prototype



Low-mass G10 Frame GEM – Beam Test (UVA)

⇨ **Test Beam @ FTBF Fermilab:** 3 weeks long joint Test Beam effort with Florida Tech (Large Area GEM) and Stony Brook University (TPC prototype) and BNL support

⇨ **Goals:** Study the spatial resolution of the large GEMs (UVa and FIT prototypes) and perform position scan for the study gain uniformity

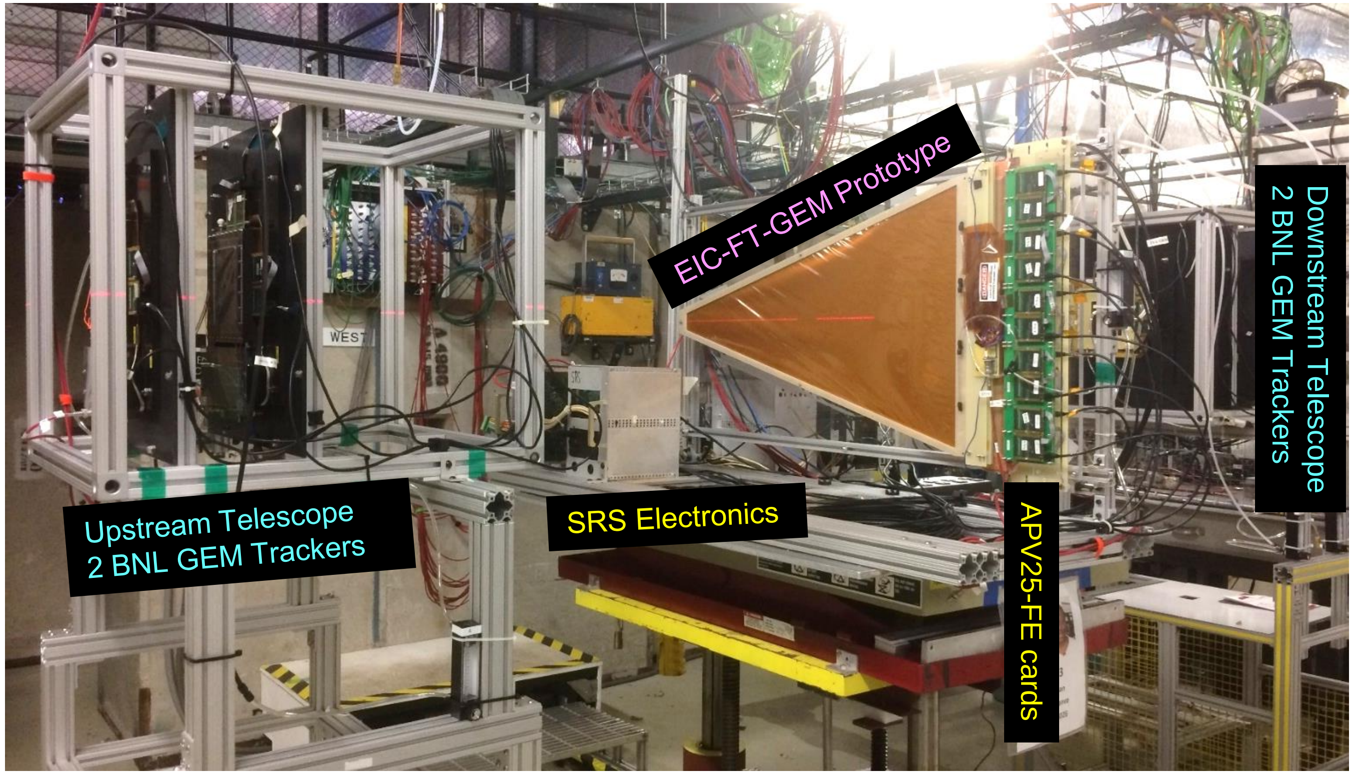
⇨ **Tracking**: Four BNL 10 cm × 10 cm GEM with 2D COMPASS readout

⇨ **Readout electronics:** APV25-based SRS Readout electronics + DATE / AMORE for the DAQ and analysis software

⇨ **Analysis of the data just started**

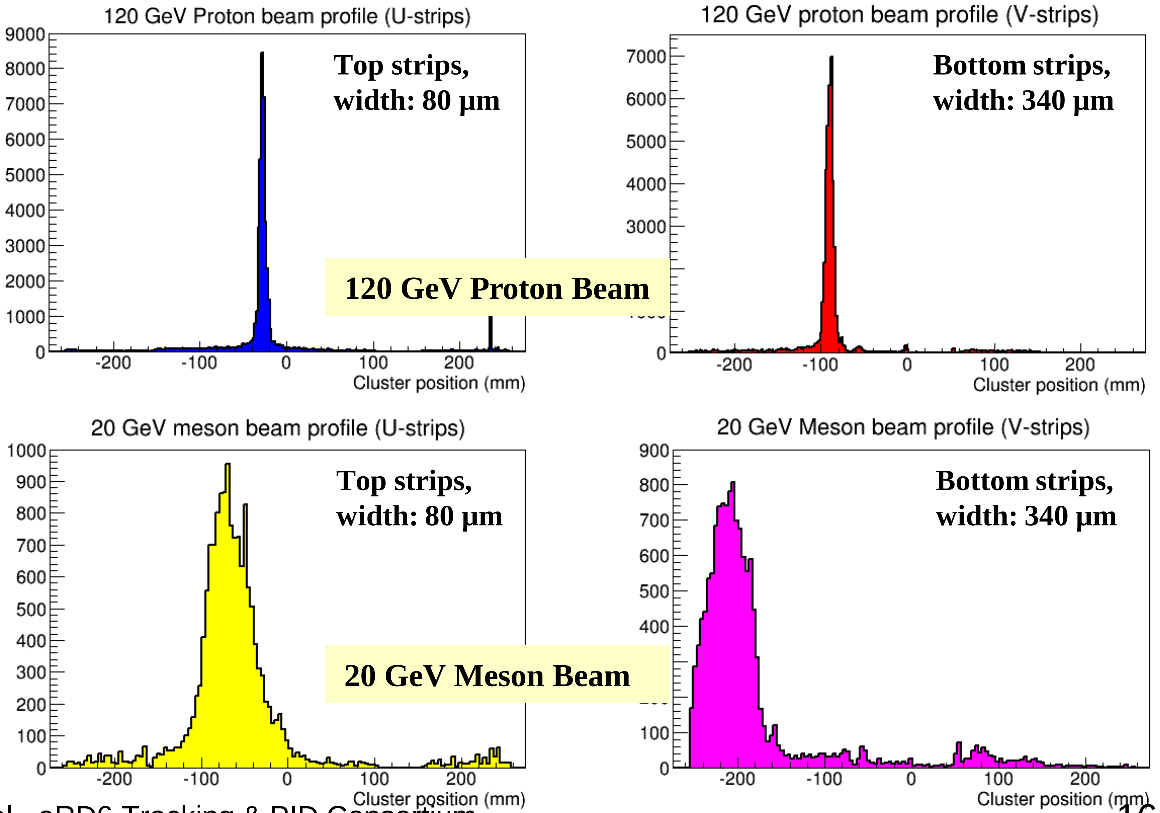
Setup @ the FTBF Fermilab (July 2018):

UVa EIC-FT-GEM with BNL GEM Telescope used as reference trackers



Preliminary results from Test Beam @ Fermilab:

Beam profile in U and V strips of the EIC-FT-GEM prototype



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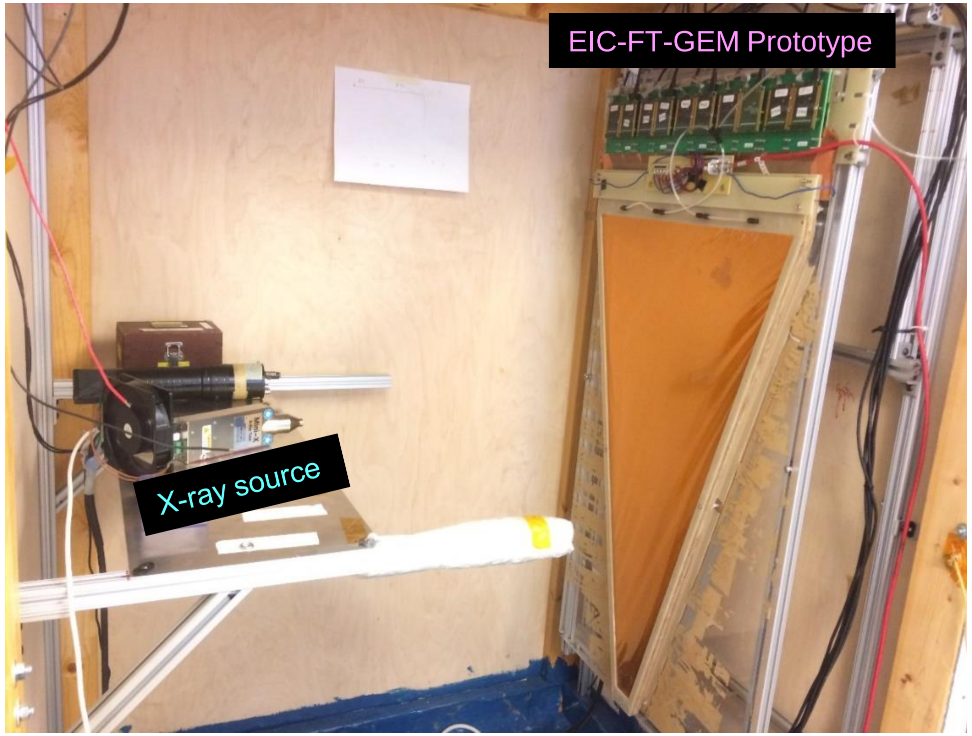
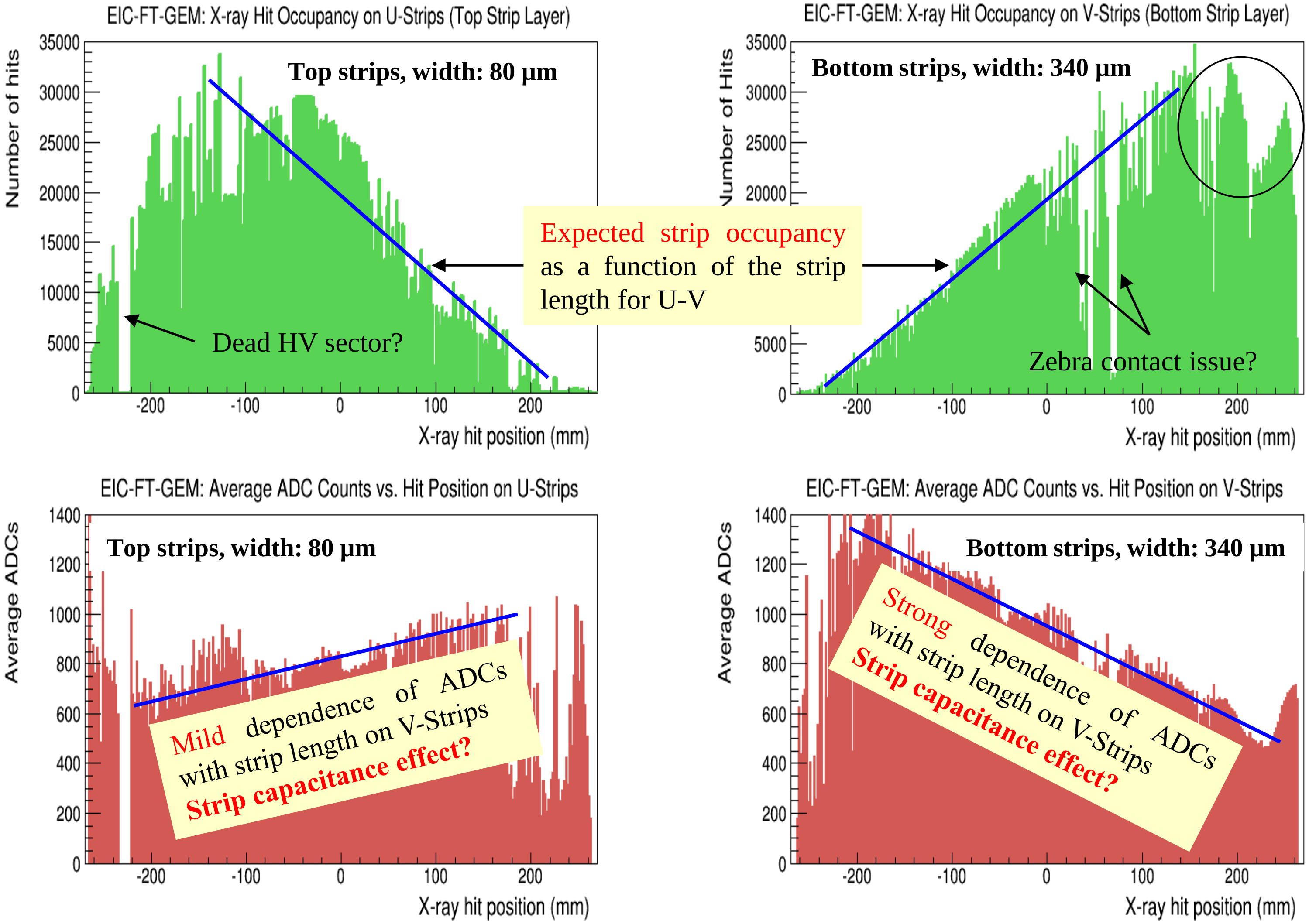
X-Ray Test in the Detector Lab @ UVa

- ⇨ Further validation of the double sided zebra connection scheme
- ⇨ Study of gain uniformity of the chamber and correlation between strip length and signal pulse size (average ADC vs. strip length)
- ⇨ Effect of charging up in high particle rate exposure

EIC-FT-GEM prototype in X-ray Test Box



Preliminary results from X-ray test: Occupancy and gain uniformity



R&D on µRWELL with 2D Readout (UVA)

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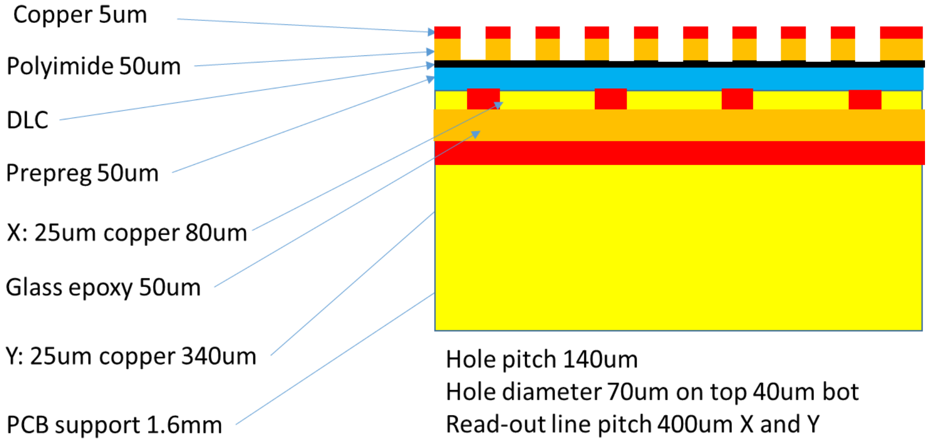
UVA

Goals / challenges of the current R&D:

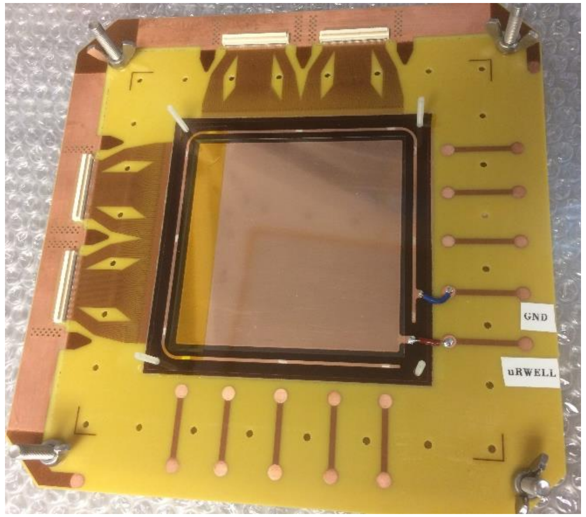
- ⇨ **µRWELL R&D:** We acquired and assembled one small 10 cm × 10 cm prototype with 2D X-Y strips readout a la COMPASS
- ⇨ **Study the performance of 2D readout strips:** X-Y strips signal are shared through capacitive coupling
  - ⇨ Charge sharing and cluster charge size (ave. # of strips with hit)
  - ⇨ Preliminary results from the test beam data
  - ⇨ non equal sharing between top and bottom strips and distortion of the charges on bottom strips
- ⇨ **Analysis of the data just started and is ongoing**

Cross section of µRWELL layer with 2D X-Y readout

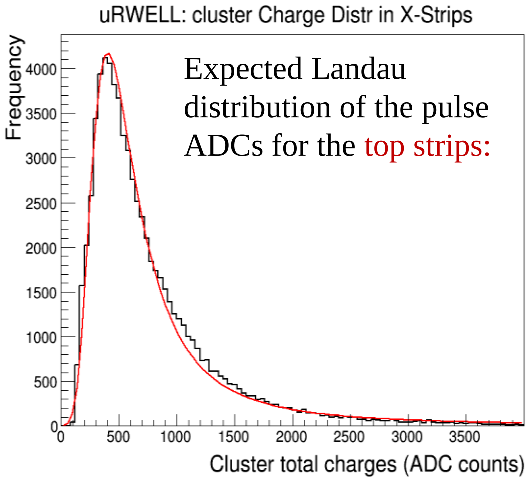


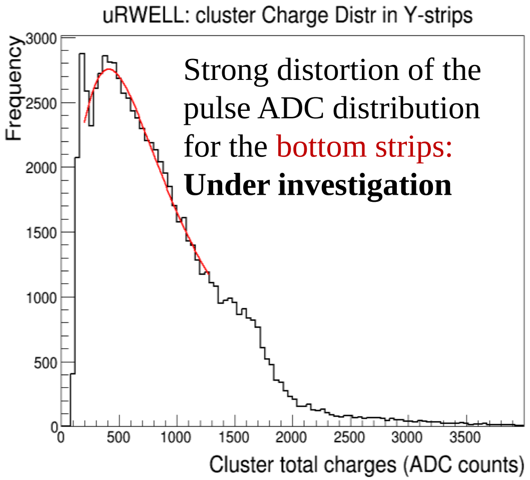
µRWELL in FNAL Test Beam

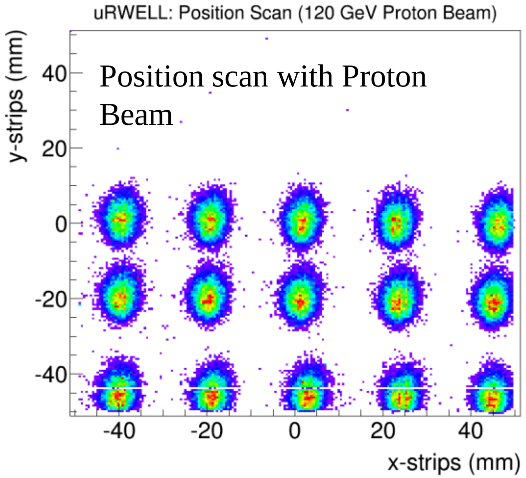
µRWELL with 2D X-Y readout



Preliminary results with the µRWELL @ FTBF (July 2018)







PARTICLE ID

Overview – Current PID R&D

- INFN Trieste
  - Single-photon detection with MPGDs for high-momentum RICH
    - Resistive MICROMEGAS prototype with miniaturized pad size
    - Nano-diamond photocathodes for MPGDs
- SBU
  - Evaporator upgrade for mirror coating

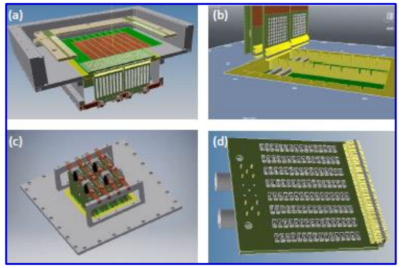
Gaseous Photon Detection (INFN)

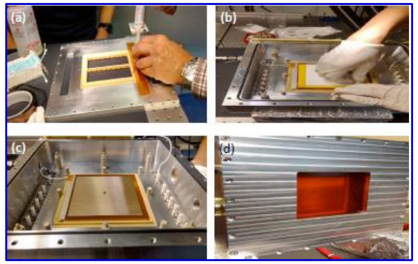
Florida Tech

eRD6 INFN

Two current tasks:

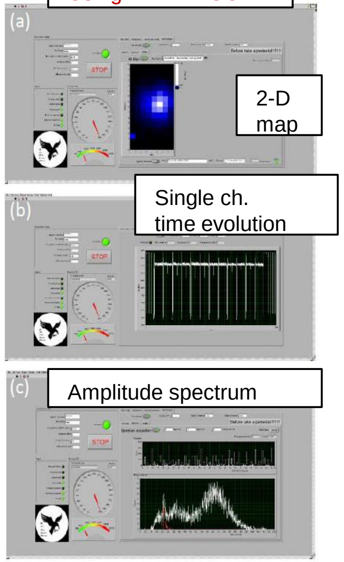
1. Development of a resistive MICROMEGAS prototype with miniaturized pad-size

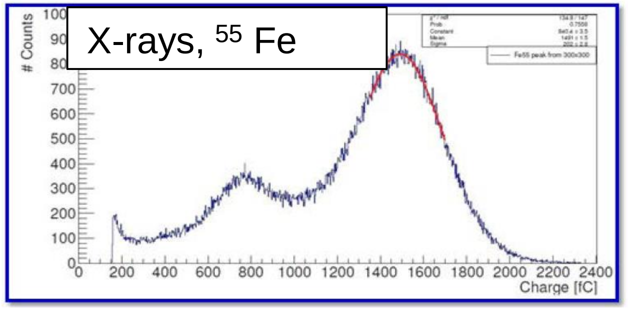


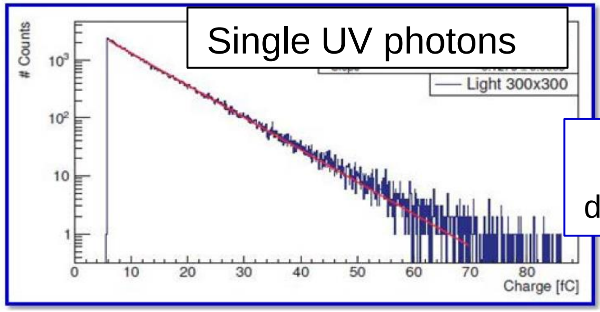


Development of an original DAQ system: RAVEN to read-out SRS electronics at maxim rate compatible with SRS

Using RAVEN GUI

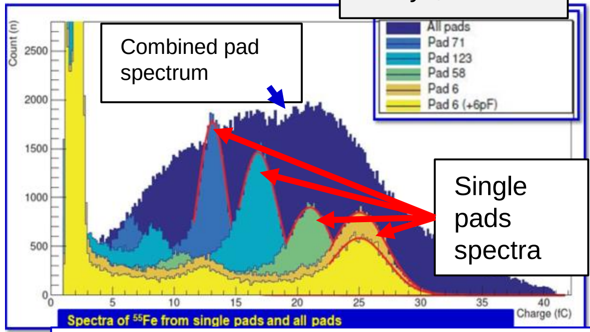






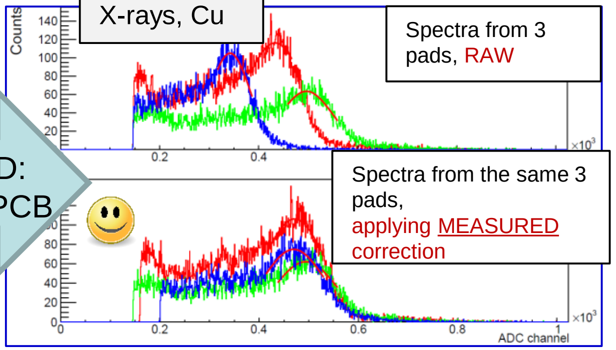
Satisfactory detector performance

X-rays, ^{55} Fe



Non uniform gain even in adjacent pads

UNDERSTOOD: Parasitic C in PCB

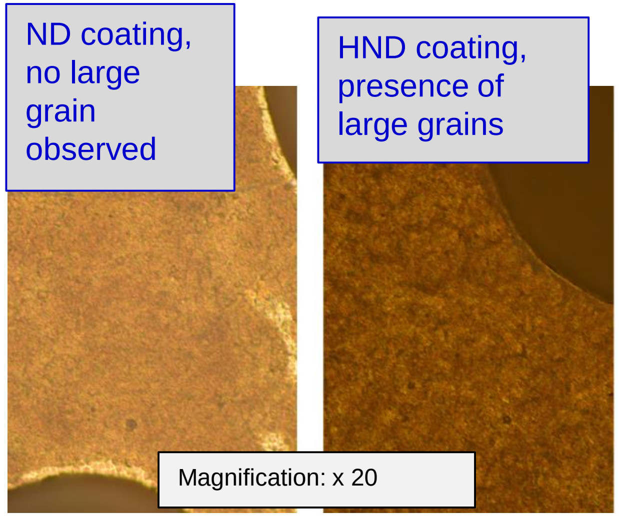


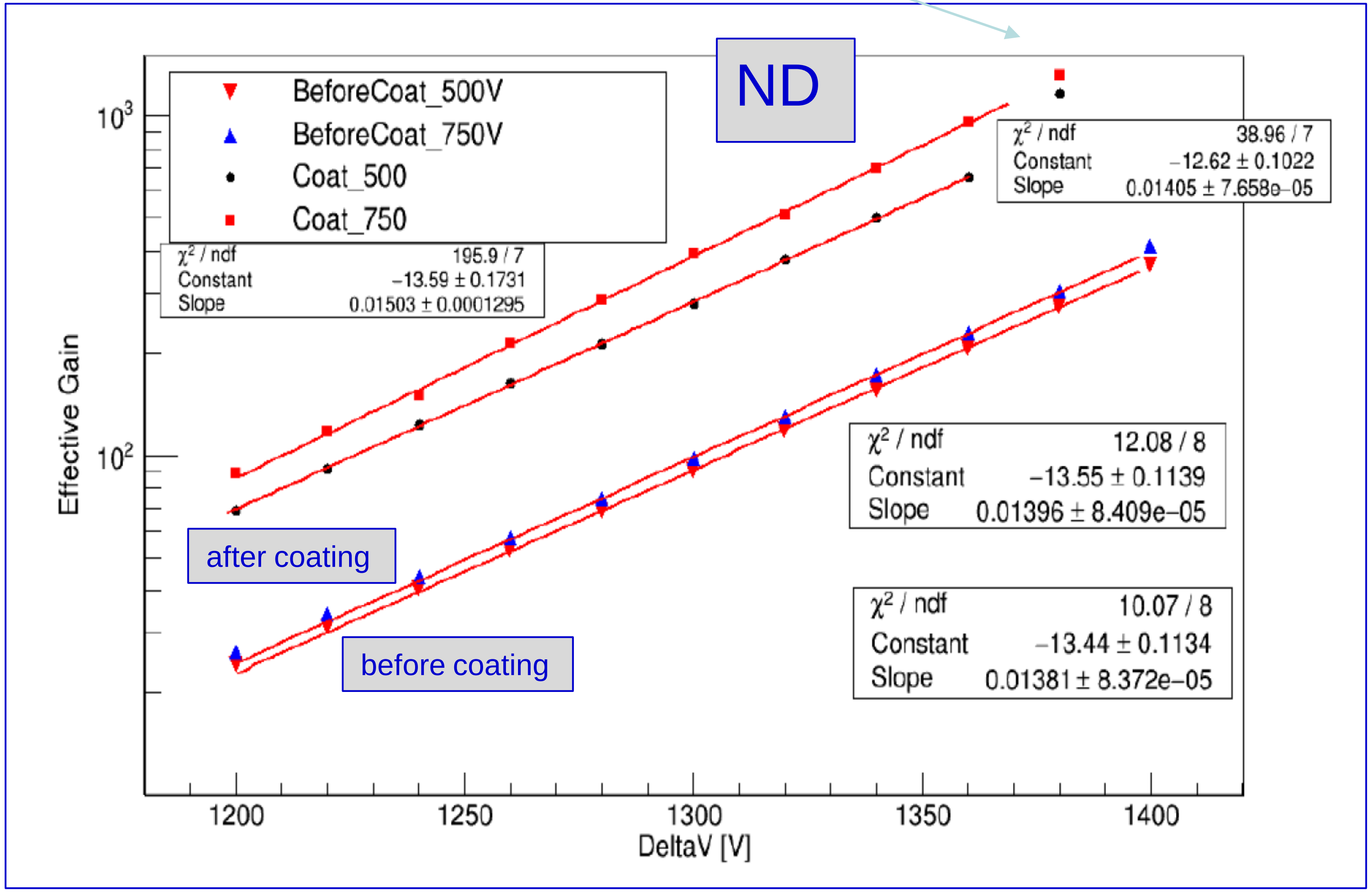
Preparation for the test beam: almost completed

Two current tasks (cont.) :

2. Initial studies of the compatibility of an innovative photocathode based on NanoDiamond (ND) particles with the operation in MPGD-based photon detectors

- Preliminary exercises
  - 6 small-size THGEMs (30 x 30 mm^2) fully characterized before and after coating with ND powder & Hydrogenated ND (HND) powder:
  - ND : systematically higher gain
  - HND : systematically lower breakdown HV, morphology ?





→ **Already indications for future studies**

Gaseous Photon Detection (INFN)

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INFN

Upcoming 2018 MILESTONES:

- September 2018: *The completion of the laboratory characterization of the photon detector with miniaturized pad-size.*

  FULLY MATCHED

- September 2018: *The completion of the tests to establish the compatibility of the ND photocathodes with the operation of MPGD-based photon detectors.*

  FIRST SET OF MEASUREMENTS PERFORMED, FURTHER STUDIES NEEDED

Evaporator Upgrade (SBU)

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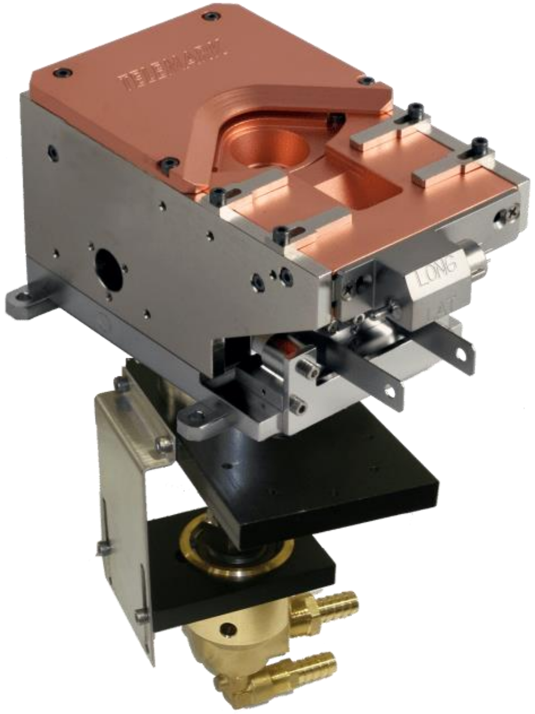
SBU

Installation of E-Beam source started at SBU



FY19 / BNL, FIT, INFN, SBU, Temple, UVA, Yale

R&D PROPOSAL

TRACKING

Overview – Tracking R&D Proposed for FY19

- BNL, SBU, Yale
  - Optimization of TPC performance at EIC
- FIT, Temple*, UVA
  - Simulation of a fast central tracker based on µRWELL
  - Design of small cylindrical µRWELL prototype
- FIT
  - Refurbishment and testing of low-mass forward tracker prototype
- Temple*
  - Test stand for material outgassing

* Temple U. joining eRD6 as a full member in FY19

TPC R&D

Motivation: Investigate new forms of readout and operating gases for a TPC that would optimize its operation for EIC.

- Aspects include:
  - Utilizing different gain structures/readout modules
  - Tuning the gain structure operating parameters (voltages and fields) for optimal performance under EIC operating conditions.
  - Optimizing the detector operating gas.

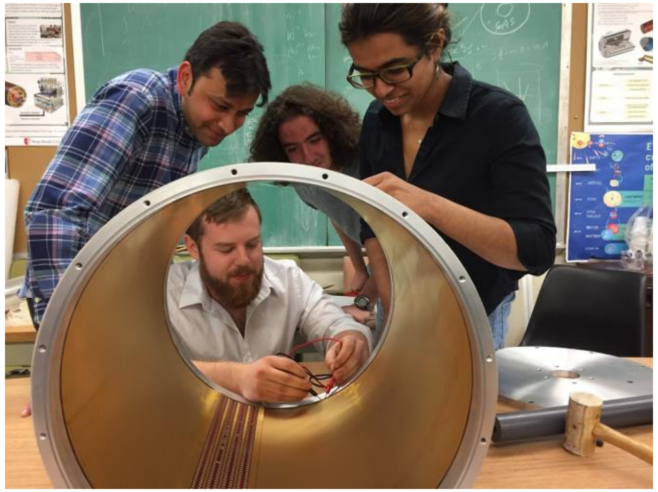
R&D collaborators: BNL, SBU, Yale

- The group at BNL has a great deal of experience with MPGD's, and has the equipment and infrastructure available to perform much of the envisioned R&D
- The group at Stony Brook is now developing the sPHENIX TPC and brings a high level of expertise for identifying and implementing areas of potential improvement for operation of a TPC at EIC
- The group at Yale has extensive experience with developing the STAR and ALICE TPC's, and has much experience with novel readout structures like GEM+MM hybrid readouts

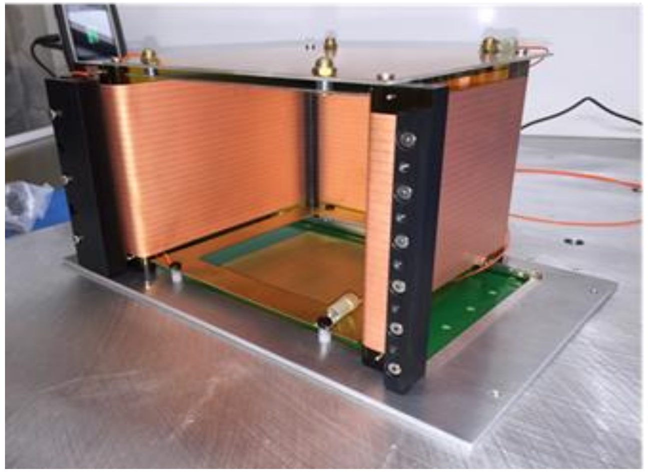
TPC R&D

Proposed R&D activities for FY19:

- Utilize both our small TPC prototype (redesigned and rebuilt from our TPC/Cherenkov) as well as a larger field cage being built at Stony Brook.
- Test with Multistage GEM, MicroMegas, Hybrid GEM+MicroMegas and Micro-RWELL readout.
- Investigate various types of readout boards (including zigzags and other patterns) and different gases to optimize readout with each type of gain structure, including IBF studies.
- Carry out simulation studies for various readout patterns and gas combinations.
- Read out the TPC prototype using the SAMPA readout electronics currently being developed for sPHENIX and/or DREAM electronics. Can also read out up to 128 channels over limited drift range using our high resolution V1742 DRS system.
- Measure spatial resolution and track resolution in a TPC operating mode using cosmic ray telescope in the lab and then in the test beam.
- Study the laser calibration of the TPC drift region using a UV laser.



Cylindrical Cage (40 cm drift)



Rectangular Cage (flexibility)

TPC R&D

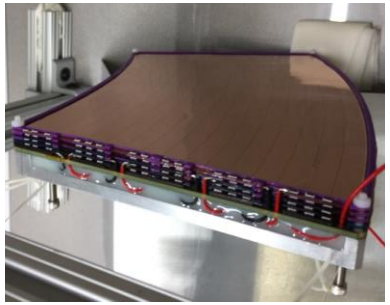
Lab Infrastructure

- Cosmic ray telescope
- Compact TPC (in lab)
- Small cylindrical TPC prototype (sPHENIX)
- 2 and 4 ch. gas mixing / distr. system
- Collimated X-ray scanner
- 32cm drift cell test chamber (up to ~2kV/cm) for gas studies
- High intensity x-ray gun
- 12 ch. pico-ammeter module (can float to 6kV)
- 266nm laser

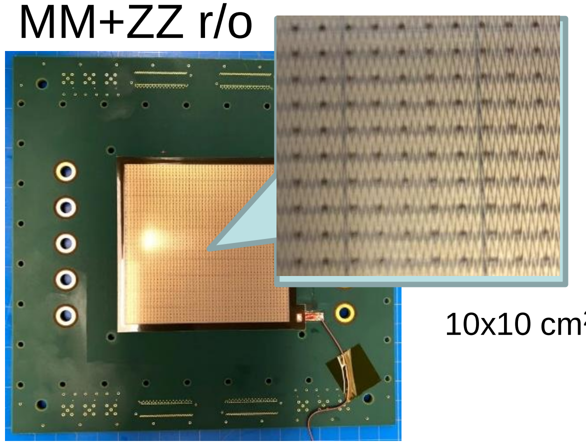
Detector Readouts to test

- 4-GEM+ ZZ r/o (Laser etched)
- 2-GEM+MM+ZZ r/o (10x10 cm^2 + sPHENIX TPC)
- μRWELL+ZZ r/o

4GEM – Minimal Dead Area

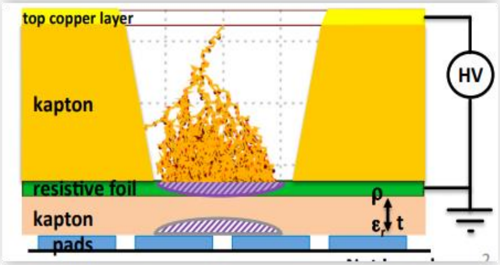


MM+ZZ r/o



10x10 cm^2

μRWELL

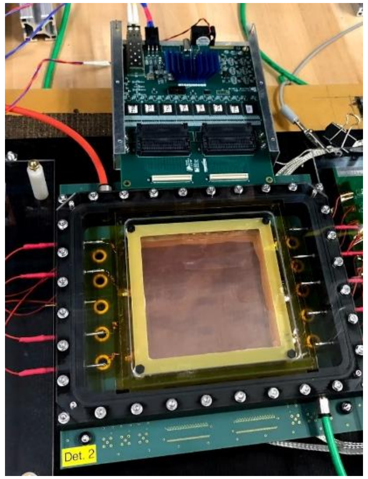


Available Readout Electronics

- 2048 ch. SRS + APV25
- 128 ch. discrete FEE + DRS4 based ADC (750MHz-5GHz sampling, up to ~1μsec long daq frame)
- ~512+ ch. SAMPA (FEE, 10-20MHz sampling, 5-10μsec long daq frame
- 1024 ch. DREAM (FEE, programmable gain & shaping time, 50MHz sampling, ~10μsec daq frame

CAEN V1742 ADC

SAMPA Eval. Bd.



DREAM Module

TPC R&D

Studies on readout structures and operation

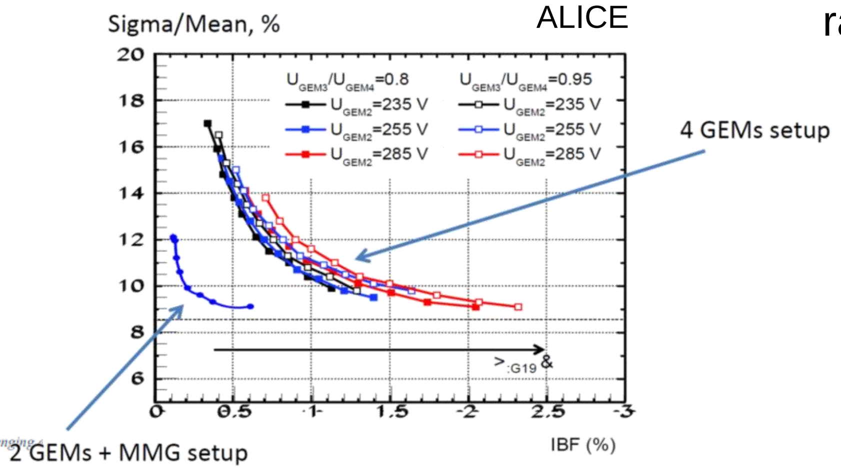
- Multistage GEMs, Hybrid GEM+MM, Micro-RWELL
- Optimize GEM configuration (hole pattern/pitch)
- Optimize fields/voltages
- Study grid structures

Gas studies

- Gain, Drift velocity (plateau region)
- Charge spread/diffusion over drift
- Primary charge in gas from ionizing track (Neff)
- Investigate possible operating gases
  - Ar-CF4-iC4H10 (95-3-2), Ar-CF4 (95-5), Ar-CO2 (90-10),…
- IBF may be a problem for EIC (especially at the ultimate design luminosity)

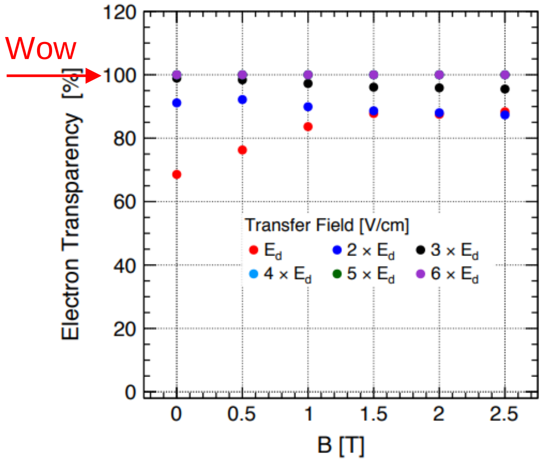
	AuAu 200 Gev	EIC (baseline)	EIC (Ultimate)
Gas	Neon	Argon	Argon
Ionization (e/cm)	43	94	94
Multiplicity	450	0.45	0.45
Rate	100	69	711
K	6.93	1.96	1.96
Dead Volume Factor	0.1	1	1
Op Point Factor	0.3	2	2
FOM	8377	2978	30689
FOM relative to sPHENIX	1.00	0.36	3.66

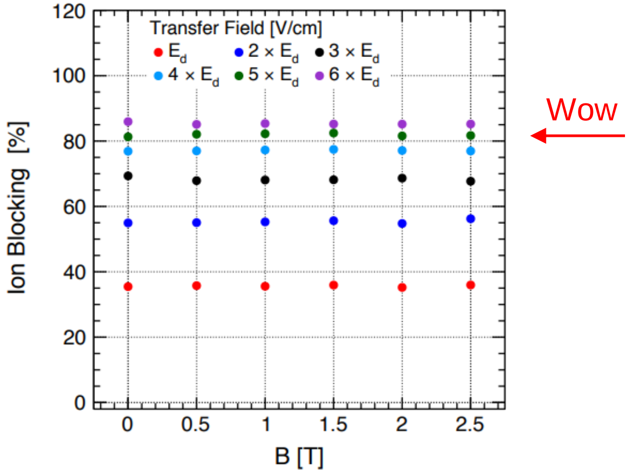
…v Figure of Merit for sPHENIX as compared to EIC. Large figure of merit indicates a more challenging…



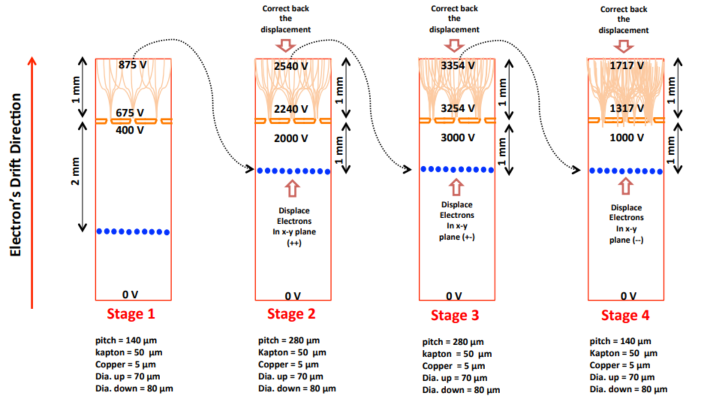
Simulations

Novel IBF structures using passive Grid.





Novel simulation of full GEMstack avalanche with random hole alignment.



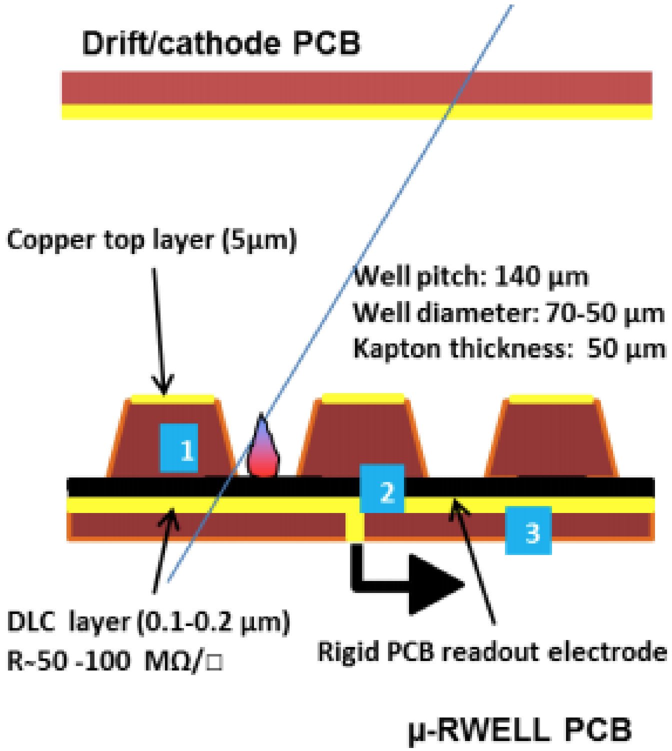
Interrupt GARFIELD shifting charge btw layers!

World's most accurate GEM simulation

Cylindrical μRWELL Detector

Motivation

- A consensus was formed within the EIC community that an EIC should ideally have **two** large detectors – preferably with **complementary technologies**.
- One detector would presumably feature a TPC in the central region while the second should seek another technology
  - One such technology that can provide fast tracking signals is the **resistive micro-well detector ($\mu RWELL$)**.
  - This technology can even serve as a fast, *prompt-hit* detector in combination with a TPC.
- $\mu RWELL$ combines the advantages of both GEM and Micromegas
  - Like Micromegas → single amplification stage, thin structure, low material
  - Like GEM → Simple and single structure
  - Unlike GEM and Micromegas → no stretching needed for detector assembly
  - Low cost MPGD detector
- The $\mu RWELL$ PCB is realized by coupling
  - A *suitable* WELL patterned Kapton foil as *amplification stage*
  - A *resistive stage* for the discharge suppression and current evacuation
  - A standard readout PCB

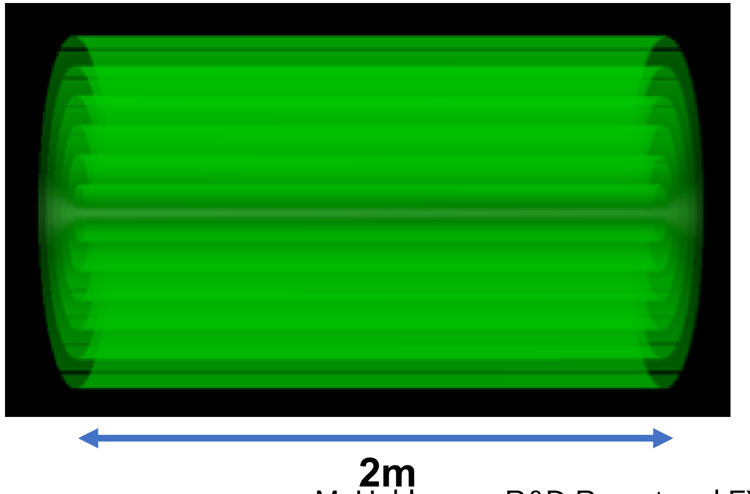


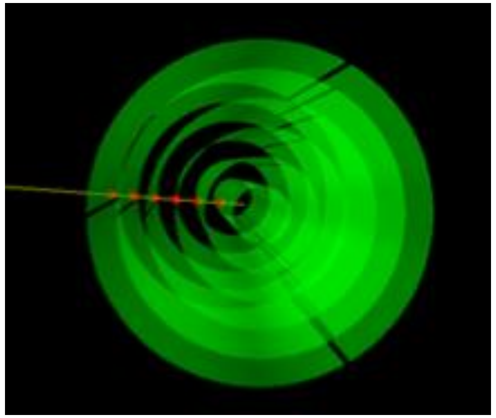
G. Bencivenni et al., 2015_JINST_10_P02008

Cylindrical μRWELL Detector

Simulation: (Temple U.)

- Within the EICRoot framework we plan to implement low-mass cylindrical $\mu RWELL$ layers and carry out a series of simulation studies to better understand the practicality and benefit of such a technology.
  1. Study momentum resolution of particle tracks as a function of cylindrical $\mu RWELL$ layers.
  2. Study momentum resolution of particle tracks (π/e) as function of energy and pseudo-rapidity using $\mu RWELL$.
  3. Repeat study 2. using already implemented TPC
- We will only be requesting money for manpower to carry out the simulation and analysis
  - Postdoc @ 20%





Preliminary low-mass $\mu RWELL$ cylindrical shells already implemented within EICRoot

Cylindrical μRWELL Detector – R&D Plan

Design of a Cylindrical μRWELL Prototype: (FIT & UVA)

- Design a low-mass cylindrical μRWELL with a diameter of 10-20 cm and a length of about 30 cm.
- Address mechanical issues related to maintaining a uniform drift gap and gas seal around a cylindrical detector
- Design of readout structures allowing to read out the signal from both ends of the detector

R&D on readout structures for cylindrical μRWELL detector: (FIT & UVA with BNL support)

- Continue the characterization of small planar μRWELL prototypes with 2D strips (UVa) and zigzag strip (FIT)
- Develop new small planar μRWELL prototypes with low mass and / or low-channel count 2D readout structures
- Design of readout structures to read out the signal from both ends of the detector

Funding Request for FIT & UVa

- R&D on small planar μRWELL prototypes with different 2D readout structures
- Manpower to carry out the design of the cylindrical μRWELL
- Part of the money request of the two institutes will be for travel to BNL for X-ray scans of the small planar μRWELL prototypes

Outgassing Test Setup (TU)

Florida Tech

eRD6

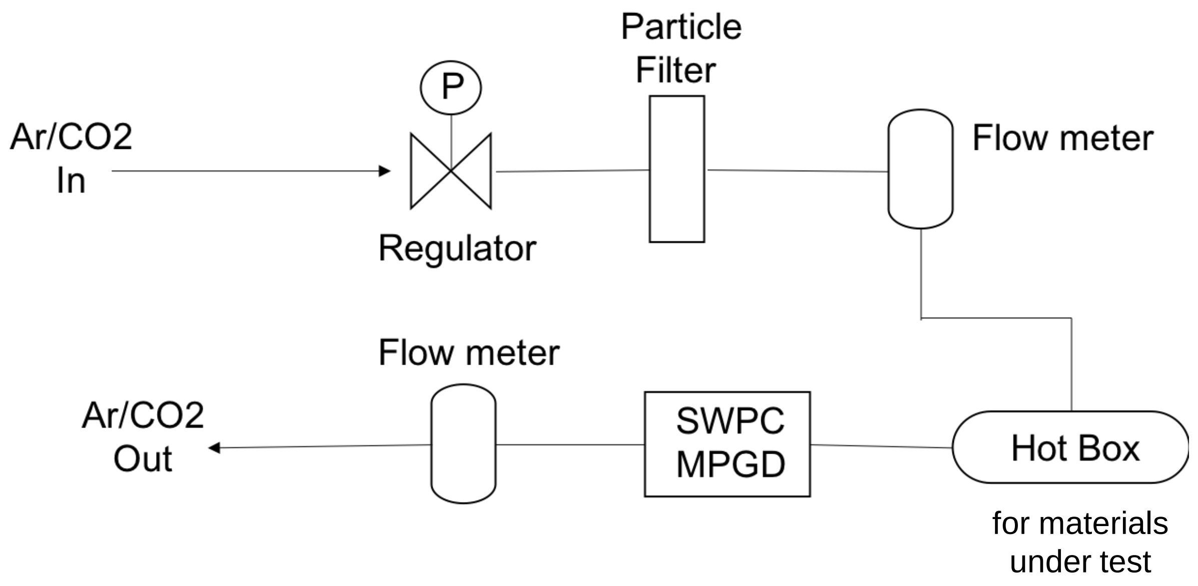
Temple

Motivation

- Test **new materials**. For example new 3D printed materials.
- Allows us to test for **cheaper alternatives** to currently used products, e.g. Nuvovern varnish.
- Provides **good synergy** with testing eRD6 3D printed GEM frame/structure R&D.
- Like the **GEM CCD** scanner at Temple University the outgas test setup would also **serve the broader detector community**, not just the EIC R&D community.

System Overview

- Follows what was done for CMS GEM testing, prepared/tested by Jeremie Merlin at CERN (we are in direct contact with him).
  - A stainless steel cylinder ("hot box") contains the material under test. The hot box is also wrapped in resistive tape to allow heating for enhanced outgassing and cleaning.
  - Clean pre-mixed gas is sent through the hot box.
  - The gas and possible pollutants are then sent to the detector (SWPC) that can measure effects of polymerization.



PARTICLE ID

Overview – PID R&D Proposed in FY19

- INFN Trieste
  - Micromegas readout with miniaturized pad size
  - Coupling a nano-diamond photocathode to an MPGD

- SBU
  - Transformation Optics Meta-Materials

PID R&D Proposal – Gasesous PD (INFN)

Florida Tech

eRD6 INFN

Near future (2019), continuation of the on-going R&D activities:

1. MICROMEGAS prototype with miniaturized pad-size
   - Test-beam in Oct 2019, followed by the analysis of the test-beam data
   - Construction of the second version of the prototype fixing the gain non uniformity and its full characterization by laboratory studies
2. Coupling of innovative photocathode based on NanoDiamond (ND) particles to MPGD photon detectors
   - Production of a new set of small-size THGEM coated with ND and hydrogenated ND (HND)
   - Full understanding of the THGEM performance and features when coated with ND and HND by laboratory studies

Corresponding 2019 MILESTONES:

- September 2019: The completion of the laboratory characterization of the second version of the photon detector with miniaturized pad-size.
- September 2019: The completion of the studies to understand the performance of THGEMs with ND coating, both in the hydrogenized and non-hydrogenized versions.

Far future (> 2019):

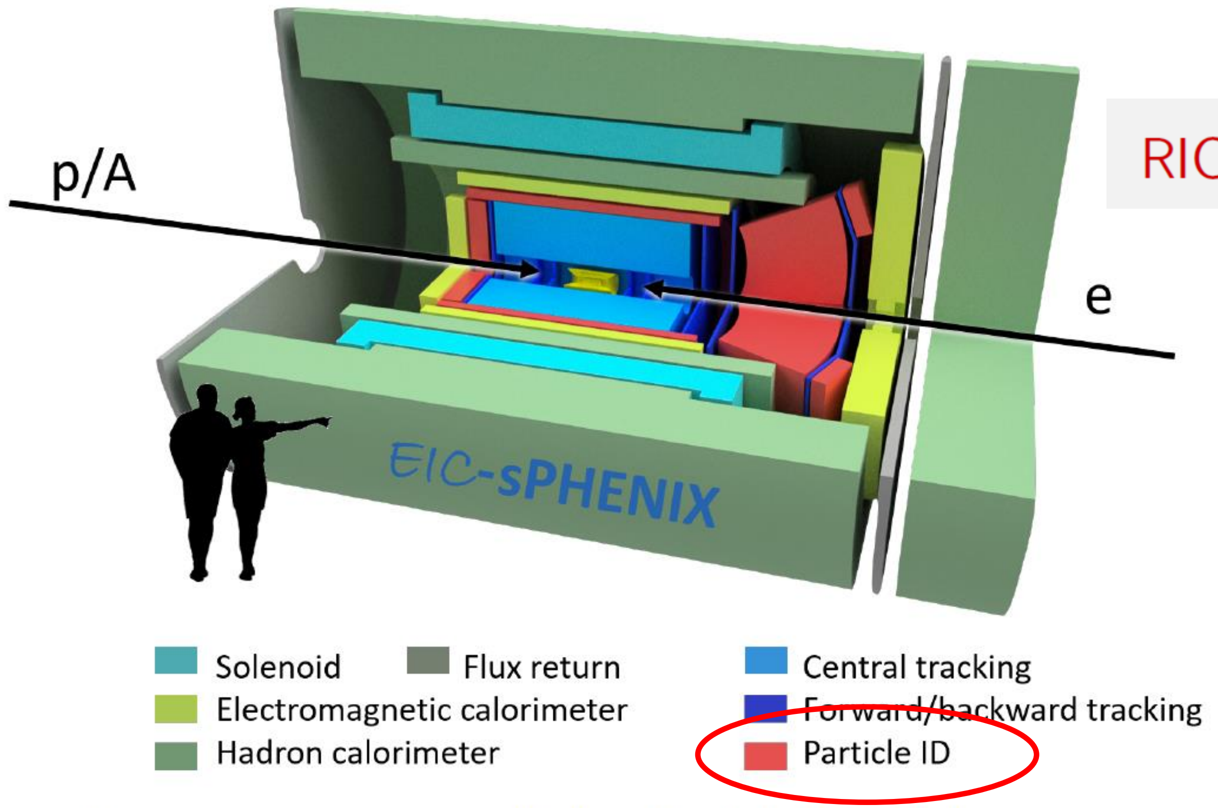
- comparison of THGEM vs GEM photocathodes in order to select the best architecture for the photon detectors of the EIC RICH;
- further studies in order to enhance the IFB suppression in hybrid MPGDs;
- operation of hybrid MPGDs in fluorocarbon-rich gas mixtures;
- *if the compatibility of ND photocathode and MPGD is established,* further studies of MPGD-based photon detectors with ND photocathodes.

PID R&D Proposal - New Materials (SBU)

Florida Tech

SBU

Motivation - Reuse sPHENIX for Day-1 EIC-Detector



Detector gets very crowded → Particle ID with least space

RICH Prototype Studies in eRD6 - 2015

Conclusion then:

- ... segmentation of the readout, we have used for our prototype is not sufficient ...
  ... radiator gas, CF_4 provides only little diffusion so that charge sharing over more than one pad on the readout plane is essentially excluded ...

Possible solution then:

- ... to overcome this limitation one has to either reduce the pad size which will result in a significantly higher channel count ...
- ... to introduce charge broadening via resistive layers, however, this introduces other complications which makes this approach less desirable ...

New Cherenkov Radiator Material

Florida Tech

eRD6

SBU

RICH Prototype Studies in eRD6 - 2018 → Proposed

Physical-/Electromagnetic-Space

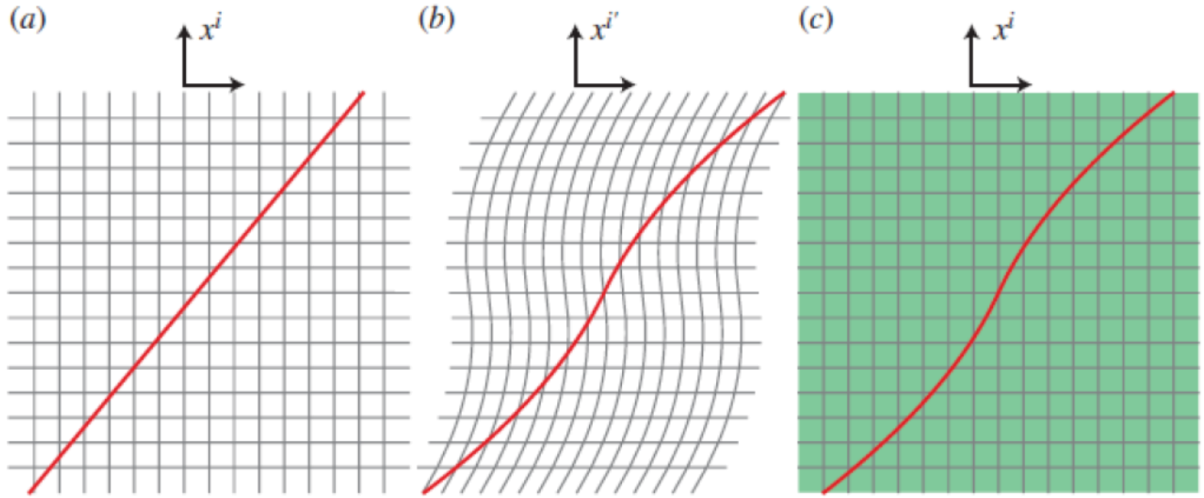
Possible solution now:

- ... to change the conditions for the radiator material in the way that it acquires properties of high index-of-refraction material in one direction and small index-of-refraction in the other direction ...
- It is conceivable that a material can be constructed whose permittivity and permeability values may be designed to vary independently and arbitrarily throughout a material
- *transformation optics* → correspondence between coordinate transformation and material implementations

Transformation Optics Meta-materials (TOM)

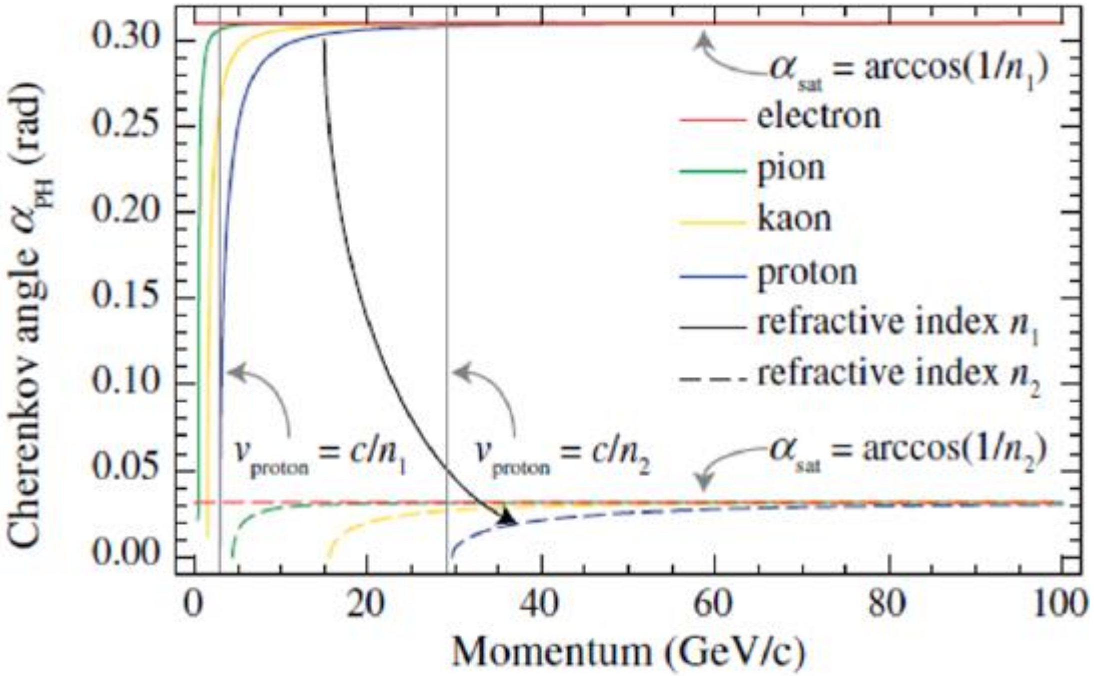
- Equivalence between geometries (Electromagnetic Space **ES**) and media (Physical Space **PS**)

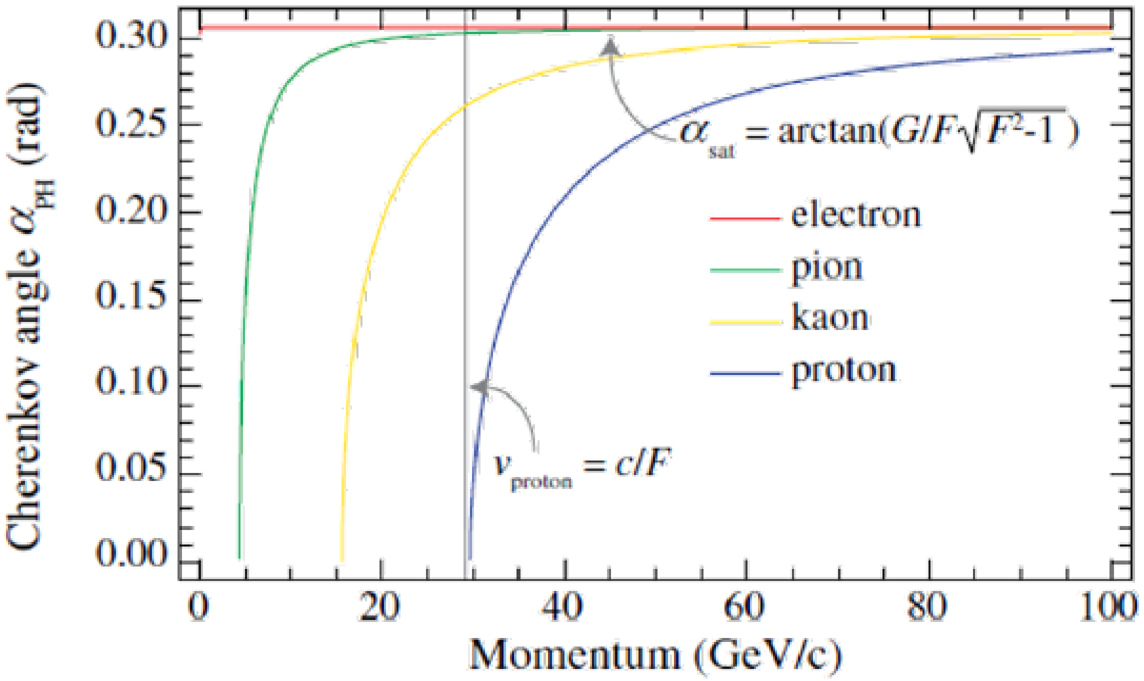
TOM Principle



(a) **ES** in Cartesian coordinate system
(b) Same **ES** in deformed coordinate system x′ $= f(x, y)$; y′=y
(c) **PS**, in which meta-material is implemented as of curved **ES** (b)

Cherenkov Angles





Aerogel vs CF_4

Meta-CF_4

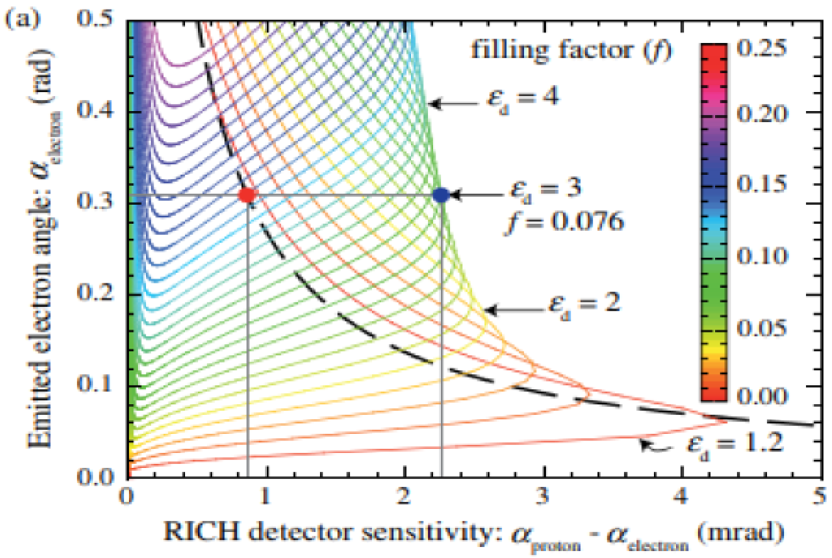
$$F = 1.0005 \quad G = 10$$

$$\tan(\alpha_{PH}) = \frac{k_y}{k_x} = \frac{G}{F}\frac{\sqrt{F^2\epsilon_b\omega^2/c^2 - k_x^2}}{k_x} = \frac{G}{F}\tan\left(\theta_{Ch,n_b}\right)$$

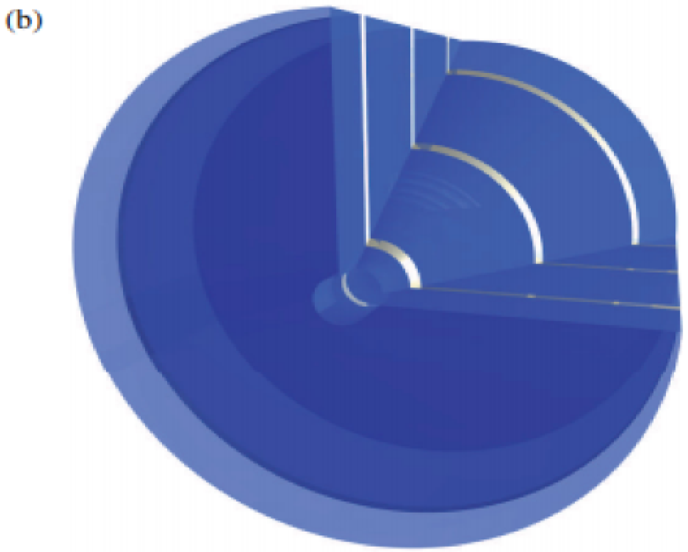
Meta-Materials for Cherenkov

Meta-Materials for Cherenkov-Radiation Detection

- Fabricate devices that provide materials with inhomogeneous indices of refraction $\rightarrow$ photonic crystals and meta-materials
- Formed by building units of size s intermediate between the molecular scale $m = (1-3)\ nm$ and the optical wavelength λ



Comparison between traditional radiators and meta-material radiators for fixed momentum (40 GeV/c) and wavelength ($\lambda = 700\ nm$)



Implementation of meta-material: Several thin silver cylinders embedded in a dielectric with $f = 0.076$

Meta-Materials R&D Plan

Florida Tech eRD6 SBU

- Perform calculations and simulations for determining the material parameters that constitute particle detectors with enhanced detection sensitivity
- Verify effective Cherenkov radiation and extend to higher dimensions (2-D and 3-D) upon 1-D photonic crystals that have been developed by industry
- Work out with commercial providers a realistic metamaterial implementation of such a detector with transparent dielectrics
- Upgrade our existing RICH prototype with photo-multipliers (SiPMs?) and adapt mirror to new detection conditions
- Anticipate performing a proof-of-principle experiment at, e.g., FTBF.

FY19

FUNDING REQUEST

Nominal FY19 Money Matrix

$k	TPC Readout	µRWELL	Material Outgassing	RICH MPGD	RICH Meta-materials	Total
BNL/Yale	75					**75**
FIT		75				**75**
INFN				50		**50**
SBU					80	**80**
Temple		23	51			**74**
UVA		25				**25**
TOTAL	**75**	**123**	**51**	**50**	**80**	**379**

- In -20% and -40% scenarios, each group reduces its request proportionally
- Details on what each group would reduce are given in the backup

The End

We thank BNL & the Review Committee for all their support!

Funding Request Details

BACKUP

µRWELL – FIT, Temple, UVA

$k	µRWELL Simulation	µRWELL Cylindrical Prototype Design	Total
Florida Tech	--	75	75
Temple	23	--	23
UVA	--	25	25
Total	**23**	**100**	**123**

µRWELL – FIT

Florida Tech - FY19 budget request including scenarios with 20% and 40% reduction.

	Request	**-20%**	**-40%**
Postdoc salary (50%, fully loaded)	$64,000	$0	$0
Graduate Student Stipend (12 mos.)	$0	$24,000	$24,000
Graduate Student Tuition	$0	$19,500	$0
Undergraduate Summer Stipend	$0	$6,000	$6,000
Travel (fully loaded)	$9,000	$9,000	$9,000
Materials (fully loaded)	$2,000	$2,000	$2,000
Total	**$75,000**	**$60,500**	**$41,000**

µRWELL – UVA

eRD6 Florida Tech

R&D Plans for FY19

Large Area & Low Mass EIC-FT-GEM Prototype

- ⇨ Analysis of July 2018 test beam data
- ⇨ Characterization of the chamber with X-ray and cosmic data
- ⇨ Present results at conferences and publication in peer-review journal

R&D on µRWELL detector technologies

- ⇨ Design of cylindrical µRWELL prototype for EIC central Tracker
- ⇨ Characterization of the small µRWELL with 2D COMPASS readout
- ⇨ R&D on small µRWELL prototypes with various 2D readout structures

VMM-based SRS Readout Electronics

- ⇨ Acquire small size SRS crate with VMM-SRS FE cards
- ⇨ Test VMM electronics on EIC-FT-GEM and µRWELL prototypes
- ⇨ Compare performances with APV25-SRS

R&D on Chromium GEMs (Cr-GEMs)

- ⇨ Characterization of the Cr-GEM prototype with X-ray
- ⇨ Present results at conferences and publication in peer-review journal

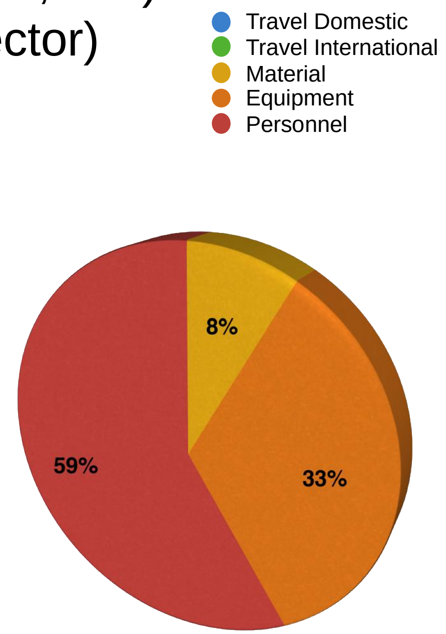
Funding Request FY19

	Request	-20%	-40%
μRWELL	\$10,000	\$5000	\$5000
VMM Electronics	\$5,000	\$5,000	\$3,000
Lab supplies	\$2,000	\$2,000	\$1,000
Travel (fully loaded)	\$5,000	\$4,000	\$3,000
Overhead (61%)	\$3075	\$2460	\$1845
Total	**\$25075**	**\$18460**	**\$13845**

Outgassing Setup – TU

Outgas Test Setup Funding Request

- We would break the outgas test setup into two building phases
- Phase 1 (this funding cycle): Build/implement
  - Gas system (stainless steel tubing, flow meters, regulators, etc.)
  - SWPC detector (we would also like to install a GEM detector)
  - Both detector kits are available for purchase from CERN
  - SRS DAQ system
- Phase 2 (next funding cycle): Build/implement
  - Pressure/Temperature sensors
  - Hot box and resistive tape
- 30% Postdoc will also be responsible for finishing eRD3 commercial GEM program (cosmic/x-ray characterization, no materials/equipment needed).
- No travel money is being requested for this project.
- Materials/equipment needed for outgas gas system, detector, and readout/DAQ.



DOE EIC R&D / eRD6 - Temple University	
	FY 2019
PERSONNEL	
Post Docs (30%)	$16,910
Fringe Benefits	
26.85% on Post Doc	$4,540
Total Personnel	$21,451
Travel - Domestic	$0
Travel - International	$0
Material	$3,000
Equipment	$12,000
OTHER:	
Total Direct Costs	$36,451
Modified Total Direct Costs (MTDC)	$24,451
F&A: On-Campus Overhead 58.5%	$14,304
Total Project Costs	$50,755

TPC – BNL, SBU, Yale

New pad plane PCB's for TPC r/o

FEE adaptor cards, pico-ammeter, LV supplies

Technician (detector assembly) and design engineer (new mods)

Beam test, face to face meetings, conferences, etc.

	Baseline (k$)	-20% (k$)	-40% (k$)
Readout boards (uniform patterns)	20	10	10
Gas and misc. electronic components	5	5	5
Technical support	10	10	5
Travel	15	15	10
Total w/o overhead	50	40	30
Overhead	25	20	15
Total with overhead	**75**	**60**	**45**

Gaseous PID – INFN TRIESTE

FUNDING REQUESTS

Table 4: Funding request INFN

item	cost (k$)	overhead (k$)	total (=cost+overhead) (k$)
manpower	20	4	24
traveling	10	2	12
consumables	14		14

Details:

1. a postdoc (7 months) fully dedicated to the project: a crucial boost to the R&D program;
2. traveling resources : within eRD6 Consortium, between Trieste and Bari;
3. Consumables: prototype components and prototype operation costs

COMPLEMENTARY INFORMATION

Personnel (globally equivalent to 3 FTE):

From INFN Trieste:

- J. Agarwala (ICTP and INFN, fellowship)
- C. Chatterjee (Trieste University and INFN, PhD student)
- S. Dalla Torre (INFN, Staff)
- S. Dasgupta (INFN, postdoc)
- S. Levorato (INFN, Staff)
- F. Tessarotto (INFN, Staff)
- Y. Zhao (INFN, postdoc)
- *technical personnel from INFN-Trieste foreseen according to needs*

From INFN BARI:

- Grazia Cicala (CNR staff and INFN)
- Antonio Valentini (Bari University and INFN, professor)

External Funding

2019 INFN support for this activity, requested: 12 k €

Reminder - 2017 INFN support : 13 k €

2018 INFN support : 12 k €

Cherenkov Meta-Materials – SBU

	Request	-20%	-40%
Photon readout	\$20,000	\$16,000	\$14,000
Mirror parts	\$5,000	\$4,000	\$3,000
Travel	\$10,000	\$8,000	\$6,000
Consumables	\$5,000	\$4,000	\$3,000
Developing meta-materials	\$40,000	\$32,000	\$24,000
Total	\$80,000	\$64,000	\$48,000

Technical Details

BACKUP

Gaseous Photon Detection

Florida Tech

eRD6

INFN

REMINDER

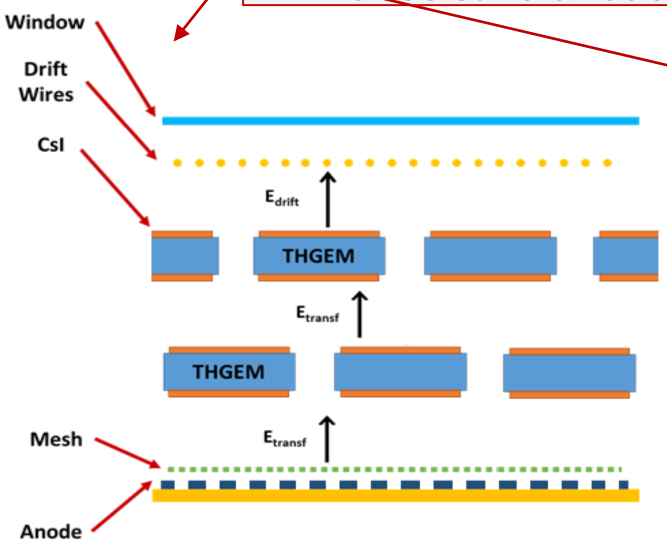
TASK: “Further development of hybrid MPGDs for single photon detection synergistic to TPC read-out sensors”

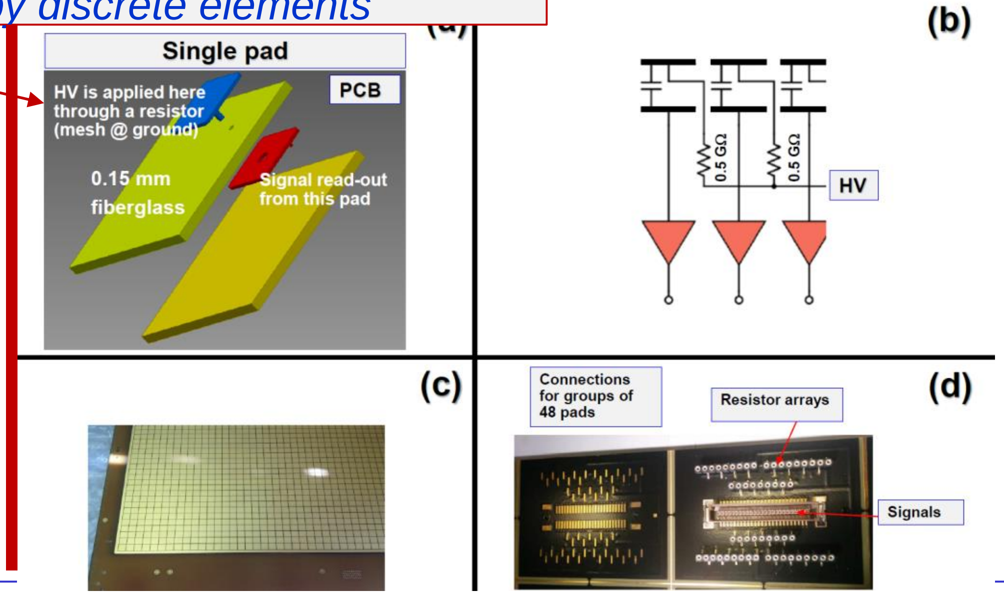
GOAL:

- further improvements of hybrid MPGD (= 2 (TH)GEMs + 1 μM, 3 stages in total)
- MPGD for single photon detection for PID, in particular high momentum RICHes
- Synergies with TPC sensors by MPGD technologies

The starting status (COMPASS RICH upgrade):

- *Scheme of the detector architecture*
- *The resistive anode by discrete elements*





Gaseous Photon Detection (INFN)

Florida Tech

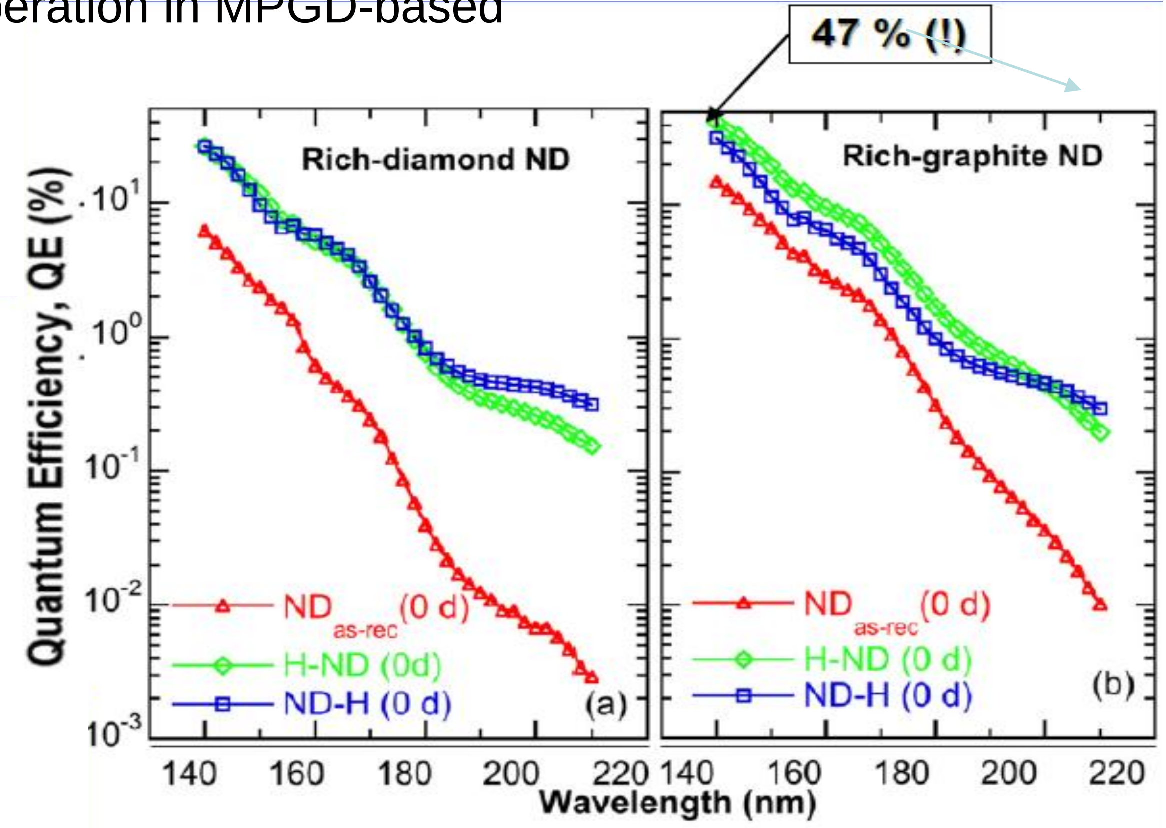
eRD6

INFN

Two tasks on-going (cont.) :

2. Initial studies of the compatibility of an innovative photocathode based on NanoDiamond (ND) particles with the operation in MPGD-based photon detectors

Reminder: the starting point



L.Velardi, A.Valentini, G.Cicala al., Diamond & Related Materials 76 (2017) 1

Cherenkov Angles

Florida Tech

eRD6 SBU

Cherenkov Photon Manipulation

- Resultant [1]:

$$\tan(\alpha_{PH}) = \frac{k_y}{k_x} = \frac{G}{F}\frac{\sqrt{F^2\epsilon_b\omega^2/c^2 - k_x^2}}{k_x} = \frac{G}{F}\tan\left(\theta_{Ch,n_b}\right)$$

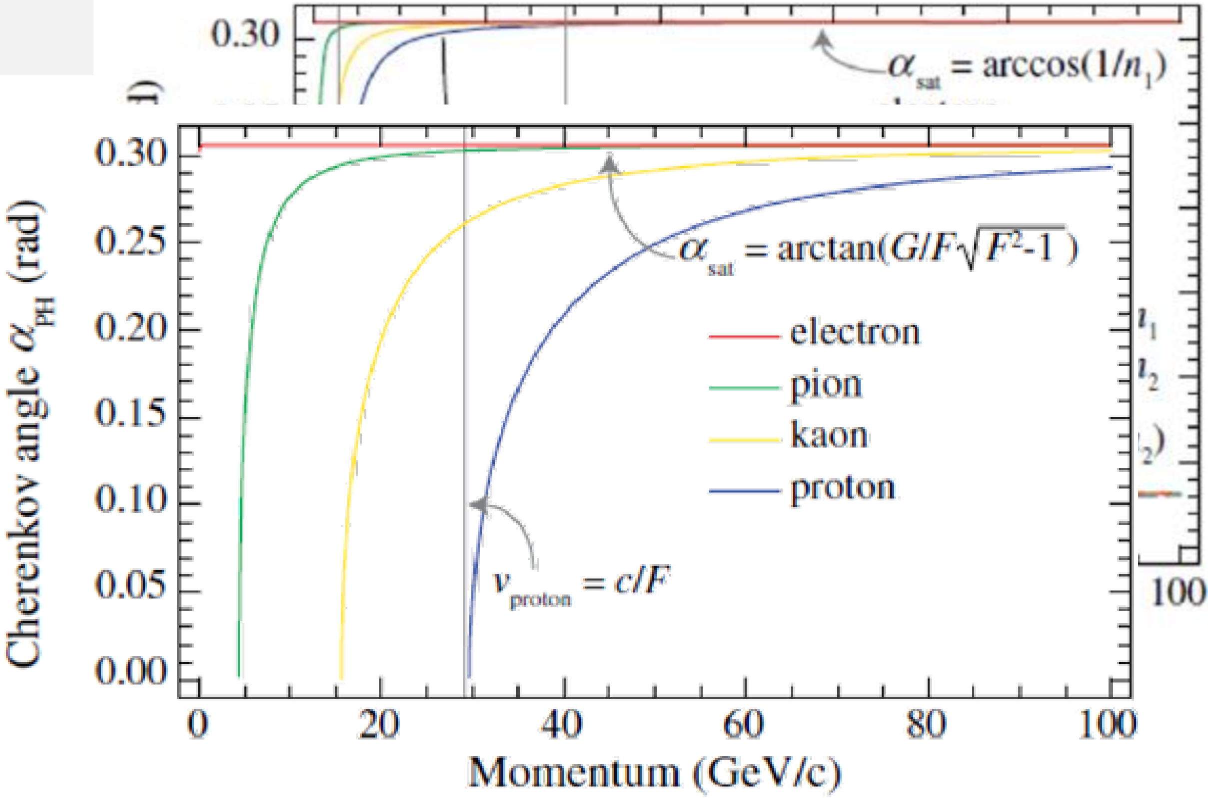
θ_{Ch,n_b}: angle of Cherenkov radiation emitted in a medium with refractive index n_b

$$\Rightarrow \alpha_{PH} = \arctan\left(\frac{G}{F}\tan\left(\arccos\left(\frac{c}{n_b F v}\right)\right)\right)$$
$$= \arctan\left(\frac{G}{F}\tan\left(\arccos\left(\frac{1}{F n_b \beta}\right)\right)\right)$$

Compare to classical Cherenkov angle:

$$\cos\theta_{Ch} = \frac{1}{n\beta} \Rightarrow \theta_{Ch} = \arccos\frac{1}{n\beta}$$

[1] $F = f', \; G = g', \; H = h'$



Meta-CF_4

$F = 1.0005 \quad G = 10$